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Bt from Hugh Hopkins

Alexr. Cuninghame Esqre.

C

AN

ELEMENTARY TREATISE

ON

NATURAL PHILOSOPHY.

TRANSLATED FROM THE FRENCH OF

M. R.-J. HAÜY,

PROFESSOR OF MINERALOGY AT THE MUSEUM OF
NATURAL HISTORY,
&c. &c. &c.

BY OLINTHUS GREGORY, A. M.
OF THE ROYAL MILITARY ACADEMY, WOOLWICH.

VOL. I.

WITH NOTES BY THE TRANSLATOR.

> ——Quid dulcius otio litterato; iis dico litteris, quibus infinitatem rerum ac naturæ, et in hoc ipso mundo, cælum, maria, terras cognoscimus!
>
> CIC. *Tusc. Qu.*

LONDON:
PRINTED FOR GEORGE KEARSLEY, FLEET-STREET.
1807.

Printed by T. DAVISON,
Whitefriars.

TO

THE RIGHT HONOURABLE

JOHN,

LORD VISCOUNT PROBY,

&c. &c. &c.

THE FOLLOWING TRANSLATION

OF

THE ABBE HAÜY'S NATURAL PHILOSOPHY

IS INSCRIBED

AS A TESTIMONY OF ATTACHMENT

TO HIS LORDSHIP'S NOBLE FAMILY,

AND OF

UNFEIGNED RESPECT

FOR HIS OWN TALENTS, PRINCIPLES, AND VIRTUES;

BY HIS LORDSHIP'S

MOST OBEDIENT AND

DEVOTED SERVANT,

OLINTHUS G. GREGORY.

PREFACE OF THE TRANSLATOR.

THOSE who have studied the history of the progress of Science and Philosophy during the last half century, will be well acquainted with the high reputation of M. Haüy as a philosopher, will have appreciated the value of his numerous discoveries, and will expect both instruction and entertainment from the perusal of any treatise written by him. It will therefore be unnecessary to attempt any eulogium upon his character, or to spend much time in convincing the English student that a treatise on Natural Philosophy by this author will amply repay him for the time and attention he may bestow upon the perusal of it. The excellent work of which a translation is now presented to the public, made its first appearance in France no longer back than the year 1803: since then it has been very widely circulated in different parts of Europe; and has been so much approved wherever it has been read, that it was conceived the translating it into our language would be performing a very acceptable piece of service to such as had been hitherto precluded from deriving any advantage from the treatise by their ignorance of the language in which it was published. M.

Haüy's object in composing this work was not to produce a compilation of earlier performances, a collection of insulated dissertations, in which every former theory shall be exhibited, but none examined; it was rather to give a cast of unity to this department of human knowledge, to present Natural Philosophy though in an abridged, yet in a complete form, to free it from a great number of superfluities with which it had been overcharged, and to develope scarcely any but theories now solidly established, though perhaps previously contested, that he might be the better able to place Physics in the situation it ought to occupy, by assigning their due portions to the comparatively recent branches of Magnetism, Electricity, Galvanism, Crystallography, &c., and by enlarging those boundaries which some modern authors seem to have established upon too narrow a space.

The Translator, after stating in these general terms the design of the Author, would refer to his masterly Introduction for such precise descriptions of the real objects of the different branches of physical science, such a luminous representation of the proper method of conducting philosophical enquiries, and such a perspicuous account of the nature of the following treatise, as cannot fail to be read with advantage before the student enters upon the performance itself.

M. Haüy's work being intended for the use of the French National Lycæum, in conjunction with Biot's valuable Elementary Treatise on Physical Astronomy, and Francœur's Elements of Mechanics, neither treats upon the subject of Astronomy nor enters into the minuter mechanical details: in this respect his plan coincides with one formed some time ago by the Translator, who, having already published treatises on

Astronomy and Mechanics which have been well received, was desirous to complete a course of Natural Philosophy. But the supplementary part of his design has been executed by M. Haüy in a manner so far superior to any thing he could himself have accomplished, that the Translator is persuaded he shall be rendering the public a more essential benefit by laying before them the present Treatise, than by offering any original performance of his own embracing the same subjects.

He has, however, during the progress of translation, thought it expedient rather than to publish the work without addition, to increase its usefulness and its correctness as far as he was able, by means of notes: in these, therefore, he has sometimes adjusted a point of history, sometimes illustrated a point of theory, and sometimes given more minute information;—he has in various instances endeavoured to do justice to English philosophers, where the Author appeared ignorant of their discoveries (for none of Haüy's omissions can be imputed to want of candour); in some few cases he has corrected mistakes which had crept into the original;—where an interesting subject was treated but cursorily, and would not admit of an ample discussion in a note, he has referred to other sources of information;—where instruments and apparatus appeared very important and admit of judicious variety, he has either explained other constructions besides those mentioned by the Author, or has made reference to well-known performances where adequate descriptions may be seen;—and lastly, he has given concise accounts of such new discoveries, new theories, &c. connected with the several topics of the Treatise, as have been made known since its first publication, or indeed, some which have come to his knowledge while the translation has been printing. The notes which have been devoted to this diversity of objects are, therefore, tolerably numerous; and it is hoped that, on the whole, they will be found of utility: but as some of them may possibly contain erroneous statements, or unsatisfactory reasonings, and the Translator has no wish that they should be ascribed to the Author, his notes are distinguished from those of M. Haüy by letters instead of the usual marks of reference (asterisms, obelisks, &c), and by placing at the end of each the abbreviation TR.

With regard to the translation itself, the Translator has been throughout desirous to convey the sense of the Author in such words as he would himself have adopted had he been well acquainted with the English language and written for English readers: and, therefore, since Haüy's style has few national peculiarities, the translation is presented as literally as the respective idioms of the two languages would allow. The translator, however, cannot help apprehending that he has sometimes failed in communicating to his expressions that elegance and spirit which are often so manifest in the original. He has, he acknowledges, in a few examples deviated from the Author's manner that he might sketch a faithful picture of his meaning: but he trusts he has in no case departed from his meaning for the sake of imitating his manner. He now commits to that public whose indulgence and liberality he has so often before experienced, a work, the design and execution of which will, he trusts, entitle it to approbation: though on the present occasion he aspires to little else than the humble merit of having translated with fidelity a very useful and popular treatise on an important branch of human knowledge.

Royal Military Academy,
May 1*st*, 1807.

⁂ A most severe and long continued domestic affliction caused this work to pass through the hands of the Translator very slowly and with many interruptions; and its melancholy termination occasioned a delay of some months, during which the last sheets were detained in the press. But this circumstance, however painfully it may press upon private feelings, would not have been obtruded upon public notice were it not to blunt the severity of criticism; and at the same time to mention that the delay may be productive of some benefit to the reader, since it has given the translator an opportunity of examining a new edition of the original work very recently imported, and of inserting at the end of the second volume the most important additions.

September 1*st*, 1807.

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INTRODUCTION.

The different points of view under which natural bodies, and the phenomena which they present, may be examined, have given rise to various kinds of study, which are multiplied as the progress of mental illumination has added new branches to the sciences already formed. The aggregate of all the knowledge thus resulting has furnished the three grand divisions, to which have been given the names of *Physics*, *Chemistry*, and *Natural History*.

If we consider in bodies their general and permanent properties, or if the changes that these bodies undergo are slight and transitory, so that the causes which produced them need only disappear, in order that the bodies may return to their former state; if, moreover, the laws which determine the reciprocal action of the same bodies are propagated to distances more or less considerable, the results of our observation remain within the dominion of physics, or natural philosophy: but when the phenomena depend upon an intimate action, which the moleculæ of bodies exercise on each other, at distances nearly infinitely small, and in virtue of which these moleculæ separate to re-unite in a different order, and produce new combinations or new properties, the study of the phenomena appertains to chemistry: lastly, if our attention is directed towards the particular beings, of which some have the enjoyment of life and spontaneous motion, others live without moving of themselves, and others have solely a structure without organisation; and, if our object be to class and to describe those beings, the point of view which is thus offered to us embraces the whole of Natural History, comprehending three sciences, distinguished by the names of *Zoology*, *Botany*, and *Mineralogy*.

In reality, all the sciences which respect natural objects compose only one and the same science, which we have subdivided in such a manner, that different minds may distribute between them the study of its various branches, and each run over the whole extent of that on which its choice is fixed. We must not, therefore, be surprised if it frequently happen that several sciences nearly meet at some one truth, so that there is no one which is not connected with others by points of contact more or less numerous. To draw an example from that which is the subject of this treatise, the modern discoveries relative to the properties of the gases, and of caloric, permit not physics to be isolated from chemistry, when the question respects phenomena, the explication of which appertains to the theory of air or of heat; for here he is the true philosopher who speaks the language of the chemist. It is the same with regard to all the parts of our knowledge; by turns they diverge from, and approach to, each other, and frequently finish by becoming confounded, as if to remind us that they all rise up again to the same unity, and that the distinction which we have placed between them proceeds solely from the limits of our mind, and those of the time which is granted us for their cultivation. We shall soon expound the plan which we have traced, to circumscribe Natural Philosophy within the limits indicated by the design of our work.

The objects which are contemplated in the study of this science furnish this advantage, that no extraordinary care or attention is necessary to find them collected about us, that the phenomena produced are of familiar observation, and that the scene on which they are developed to us is incessantly present. The experiments, in which are employed the instruments constituting our cabinets of natural philosophy, are nothing else than imitations of these phenomena, destined to unveil to us their causes. Thus, the operation of the air-pump teaches us the properties of the fluid which we respire: the effects, so striking to our curiosity, which are shewn by the electrical apparatus, assist us in determining the laws which regulate the fluid accumulated in a stormy cloud: the magnet, which seems to command the motions of the needle in a mariner's compass, when presented to its action, is, as it were, a momentary substitute for the terrestrial globe which continually exercises upon the needle an action of the same kind: the coloured image of the sun, projected by the light that has traversed a prism, gives us an idea of the decomposition undergone by the same fluid in a cloud, which, at the moment when it becomes resolved into rain, displays the magnificent spectacle of the rainbow. All these instruments so diversified, are so many interpreters of the visible language in which nature is incessantly speaking to us.

This word *Nature*, which we so frequently employ, must only be regarded as an abridged manner of expressing, sometimes the results of the laws to which the Supreme Being has subjected the universe—at others, the collection of beings which have sprung from his hands. Nature, contemplated thus under its true aspect, is no longer a subject of cold and barren speculation with respect to morals: the study of its productions, or of its phenomena, is no longer bounded to enlightening the mind; it affects the heart, by kindling therein sentiments of reverence and admiration at the sight of so many wonders, bearing such visible characters of an infinite power and wisdom. Such was the disposition that was cultivated by the great Newton, when, after having considered the mutual connexion which subsists among effects and their causes, and makes all the particulars concur to the harmony of the whole, he elevated his mind to the idea of a Creator and Prime Mover of matter, and enquired of himself why nature had made nothing in vain? whence it happens that the sun, and the planetary bodies, gravitate the one towards the other without any intermediate dense matter? and, how it could be possible that the eye should be constructed without the knowledge of optics, or the organ of hearing without the intelligence of sounds? *

The true method to arrive at the explication of phenomena, is that which was adopted by the same philosopher (Newton); and to which the sciences are indebted for the rapid progress they have made, and are still making every day in the hands of so many learned men. That it may be better conceived in what this method consists, it will not be useless to establish in this place, clearly and precisely, the idea which should be formed of that which is called a *theory*, to make its design and its advantages sensible, to trace the limits by which it is separated from a system, and to prevent

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* *Opticæ Lucis*, lib. vii. quæst. 28.

the confounding of the productions of genius which exhibit nature such as it is, with those of the imagination, which shapes it as it will.

The object of a theory is to connect to a general fact, or to the least possible number of general facts, all the particular facts which seem to be dependent. Our first steps in the sciences are directed towards the research of facts: our next employments are to describe them exactly, to verify them strictly, and to multiply them. The former are given by simple observation, and are presented as of themselves to an enlightened attention; the latter are the results of experiments made with that care, that address, and that sagacity, which this kind of researches require. All these facts, discovered at different epochs, and by different observers, stood, at first, as isolated particulars; some of them even presented themselves under the air of paradox, and seemed to stand in contradiction with the other facts of the same kind. Thus the ascent of water in the body of a pump, limited to the altitude of 33 feet, shews the defect of the obscure and unintelligible physics of that time, which attributed this ascent to a pretended horror of nature for a vacuum. But at length appeared the genius, to which was reserved the praise of re-uniting all these scattered links, and forming a continued chain, which would shew their descent and mutual dependance.

Thus, the theory of universal gravitation refers the celestial motions, the flattening of the earth, and the great phenomena of nature, to the sole fact proved undeniably by observation, that the force of gravity acts in the inverse ratio of the square of the distance. By the aid of a similar law, demonstrated by experiment, relative to the electrical and magnetical actions, we see that the different effects upon bodies solicited by these actions grow, so to speak, the one out of the other, by proceeding from a common origin. The words *attraction* and *repulsion*, which serve to indicate the fundamental fact on which the theory rests, only express properly the velocities with which the bodies tend to approach to, or recede from, each other. The essential point is, that, knowing the law to which this tendency is subjected, and applying it to the calculus, one may determine all the other facts which flow as corollaries from the former; and even the theory has this advantage, that, by its assistance, one may in future speak with certainty; because it follows from the connexion of facts once established, that what has been becomes a sure guarantee of that which will be; so that it will depend upon the calculus, by making a few steps, to call before us a phenomenon which would not be presented till after a series of years, and to give to it an anticipated existence.

Thus observation and theory concur equally to the certainty and to the developement of our knowledge. Each has a flambeau in her hand: observation directs the rays which emanate from her's upon every fact in particular, in such manner, that the whole is placed as it were in day-light, that it becomes distinctly terminated, and that it is presented to us under its true form: theory illuminates the aggregate of facts, and re-assembles, under the light of her torch, all those facts, at first dispersed, and which seem to have nothing in common; then they assume the air of a family, and appear to be nothing more than different aspects of a single fact,

It is now easy to judge how wide is the distance between a system and a theory: but we shall commence by observing, that the word *system* may be taken in a favourable acceptation, when it is employed to denote a disposition of objects relative to the sciences. Mathematicians make use of it to express the aggregate of bodies retained in connection by their mutual actions. In the language of the higher physics, it denotes the arrangement of the celestial bodies about a common centre. Naturalists have also their systems, which consist in such a methodical distribution of beings as is proper to facilitate the study.

But a system, such as we would consider here as what ought to be banished from natural philosophy, consists in a purely gratuitous supposition, to which we endeavour to confine the course of nature. It is a vortex, it is an effluvium of subtile matter; it is any thing that we please, for all is possible to the imagination. By the aid of this supposition, which always goes beyond the facts given by observation, all is explained in a vague and loose manner, satisfactory notwithstanding in this, that it does not cost more to comprehend it than to invent it originally. Hence the system proceeds as at hazard; always wandering *near* the point, but incapable of determining any fact with that precision, that rigour, which constitutes the character of the true theory: in a word, the system is the romance of nature, while the theory is its history, and a history which, without ever ceasing to be faithful to truth, embraces at once the past, the present, and the future.

We will now give an idea of the order which we have followed in the distribution of the particulars which are the objects of this treatise, confining ourselves to the announcing those which are most remarkable.

We shall first explain the most general properties of bodies, commencing with those which attach most intimately to the nature of those beings, considered simply as assemblages of material particles: such is, for example, the divisibility, or the faculty which bodies have of being always separated into smaller parts. The other general properties depend upon certain forces that solicit bodies; such are, in particular, gravitation and affinity. After having developed the laws of the descent of bodies, we shall compare affinity with gravitation, and shall lay down an hypothesis, by means of which we may refer both to the same principle. We shall take occasion, when treating of specific gravity, to explain the method which has been followed in the determination of the unit of weight in the new metrical system, and shall join to this exposition an abridged table of the system taken altogether.

With regard to affinity, we shall endeavour especially to present an idea of the theory relatively to one of its most remarkable results, namely, the symmetrical arrangements of the moleculæ of one class of natural bodies under forms similar to those of Polyedræ in geometry.

Thence we shall proceed to the consideration of another force, viz. that of caloric, which balances more or less that of affinity, and often ends by destroying it. We shall then treat in succession,—the equilibrium of caloric,—the manner in which one part of this fluid is combined with bodies, while another part escapes under a radiant form,—specific heat,—the effects of caloric in dilating bodies,—the passage from the solid to the liquid state, and from that to the state of elastic fluids. After that we shall enter upon several details relative to the variations of volume, of which solid and liquid bodies are susceptible; and the part of these details which concerns fluids will furnish an opportunity of expounding the principles on which the construction of the thermometer is founded.

From all those different branches of knowledge which properly appertain to general physics, we shall pass on to those which embrace particular physics, and which have respect to certain liquids, or to certain fluids, remarkable for the influence which they exert in a multitude of natural phenomena.

The first of these is water, which we shall first consider in its most ordinary state, that of liquidity, and which will lead to the principles of hygrometry, and to the explication of the phenomena of capillary tubes, and the apparent attractions and repulsions of little bodies floating upon water at small distances from one another. We shall then direct our attention to water in the state of ice, and shall, on that occasion, present the history of the congelation of mercury, explaining the results by the aid of which the true degree of cold to which that corresponds has been determined. Finally, we shall treat of water in the state of vapour, and shall point out the advantage which human industry has drawn from the great elastic force exerted by water in that state, when applied as a moving force to the motions of steam engines.

The properties of air will then fix our attention: we shall consider the gravity of this fluid, its spring, the effects of its pressure in elevating and depressing the mercury in the tube of a barometer, in elevating the water in the body of a pump, and in determining the play of the siphon: the law according to which the density of the air decreases in proportion as the strata of this fluid are distant from the earth's surface, will furnish us with the theory of the method of measuring heights by means of the barometer: thence we shall pass to the effects of caloric in dilating the air or augmenting its elasticity: we shall explain, when speaking of the former effect, the new researches which have led to the determination of the ratio according to which all the gases dilate from the temperature of the freezing point to that of boiling water.

In the succeeding article we shall shew how evaporation is produced by the union of water with air, and what is the law to which the dilatations of gases and vapours are generally subjected when they are blended together; afterwards we shall add some details relative to winds and aqueous vapours. From thence we shall return to the effects of evaporation in order to deduce the origin of fountains; and after having run over the most general results of the properties of the air, we shall give the history of the discovery which has procured to man the art, till then unknown, of raising himself in this fluid, and of sailing therein by the assistance of air-balloons,

The air will be considered, lastly, as the vehicle of sound, and as receiving from the parts of sonorous bodies a vibratory motion which gives rise to comparative sounds, We shall establish the series of relations from which our musical scale is formed, and shall exhibit the experiments respecting harmonical sounds attributed to Sauveur. We shall compare the gamut of the bugle horn with that which is in common use, and which has its source in perfect consonance, and we shall present the reasons which appear to decide the preference in favour of this latter; proceeding from thence to some details relative to temperament. The manner in which sound is formed in wind instruments will assist us in explaining how it is propagated in a medium of unconfined air, and how different sounds traverse this fluid without mutually disturbing each other, and convey to the ear impressions which are simultaneous at the same time that they are distinct.

When arrived at the exposition of electrical phenomena, we shall give to the developement of that branch of physics an extent proportionate to its importance. We shall first treat of the electricity produced, either by friction or by communication; and after having established the distinction existing between different bodies relatively to the two modes of electrisation, we shall propose the hypothesis of two fluids whose actions are combined in the production of the phenomena, as that which furnishes the most happy and simple manner of comprehending them. We shall next describe the experiments which demonstrate that the electrical actions follow the inverse ratio of the square of the distance; and shall deduce from that law the consequences which result with respect to the tendency of the electric fluid to disseminate itself entirely over the surfaces of conducting bodies, and to the manner in which it distributes itself between different bodies in contact. We shall then apply the preceding principles to electric attractions and repulsions, to the power of points to sustain or energetically to dart the electric fluid, to the commotion which accompanies the experiment of the Leyden phial, and to the effects of particular instruments; among others the electrophorus and the condenser. At the end of this article we shall place an exposition of the observations which have served to establish the identity of the electric fluid and the substance of lightning, the theory of *paratonneres*, with reflections on the advantages of those instruments, and the theory of the singular effect called the *returning stroke;* and which consists in this, that a person is sometimes effected by the thunder far from the original place of the explosion.

Another mode of electrisation which obtains by the intervention of heat, relatively to various species of crystallised minerals, will furnish us with several details upon the electrical actions of those bodies, and upon the correlation which has been observed between their forms and the position of the poles in which the two opposite electricities reside.

In this place a new branch of physics presents itself, under the name of *Galvanic Electricity*, and of which the true principle is deduced from the phenomenon discovered by Volta, of an electricity excited by the simple contact of two different metals. We shall first relate the experiments performed by Galvani on cold blooded animals, and the consequences which have been deduced from them; afterwards we shall develope the theory of the celebrated Pavian philosopher, making the application to the pile which bears his name, and to the different effects which it produces. Thence we shall pass to observations made upon electric fishes, such as the torpedo, whereof the properties known long ago appear to be derived from a structure analogous to the disposition of the elements of the pile. We shall next shew how the Galvanic electrity united on one part to the animal economy, has been drawn into the domains of chemistry by the phenomenon of the decomposition of water; and we shall finish by re-uniting in one view the totality of those reconciling facts which tend to exhibit to us in Galvanic electricity nothing else than a modification of ordinary electricity.

The resemblance existing between the laws which regulate the action of magnetic bodies and those of idio-electric bodies, naturally place the theory of magnetism by the side of that of electricity: we shall therefore adapt, in like manner, in reference to the explication of magnetic phenomena, the existence and the simultaneous action of two different fluids. But here the necessity in the developement of the theory of causing the consideration of the magnetic action exerted by the terrestrial globe to intervene at each instant, requires that we previously give an idea of that action, and of certain general facts depending upon it. We shall then proceed to explain the method which has served to prove that the law presiding over the phenomena of magnetism conforms to the inverse ratio of the square of the distance, as does that on which the electric phenomena depend. From this we shall go on to the explication of the effects produced by the magnets which we have at our disposition, such as the attractions and repulsions: and we shall clear up the species of paradoxes presented by several of these effects; particularly that which results from this circumstance, that a detached portion of a magnet becomes suddenly itself a magnet, provided with its two poles. Pursuing the application of the theoretic principles to different methods of magnetising, especially to that of double contact, we shall analyse these effects, at the same time that we shall indicate the most advantageous modes of employing them.

In the last place we shall return to a more detailed account of natural magnetism, and shall set forth all that observation and theory teach relative to the declination and inclination of the magnetic needle, to the variations of both in consequence of a change of place, or of a succession of time in the same place, to those local and transient perturbations which the French call *affollemens*, to the singular phenomena produced by the magnetism of the globe upon unmagnetic bars of iron, and other similar bodies exposed to its action; and lastly to the state of habitual magnetism, in which the different mines of iron dispersed within the bosom of the earth are found in virtue of the same action.

We have reserved for the end of the work the most delicate of all the theories, namely that which relates to light. We shall first discuss the two opinions, of which the one makes this fluid consist in an emanation from luminous bodies, and the other supposes it diffused through all the sphere of the universe, and animated by a vibratory motion communicated to it by the same bodies; we shall adduce the reasons which ensure the preference to the former opinion. We shall shew in what manner we have attained a measure of the velocity of light, and shall place at the end of these prime notions the description of the aurora borealis, considered simply as a phenomenon of light, of which the cause has not yet been well determined. Then we shall exhibit the laws of the reflexion and refraction of light, and the most general effects of these two species of deviation, in the case where the incident rays meet a concave or convex surface. A closer examination of the same subject will present us with an opportunity of considering the mutual relations of reflexion and refraction, and to refer the physical explication of both to an action which is exercised at distances almost infinitely small: we shall again find the same action in the phenomenon known under the name of the *inflexion* or the *diffraction* of light. To complete this theory of the forces which bodies exert upon the luminous fluid, we shall develope the results by whose aid Newton has read, in some sort, in the laws of refraction combined with the density of bodies, that the diamond is combustible, and that water contains an inflammable principle.

In the next place we shall proceed to the discoveries of Newton on the nature of light considered as a mixture of an infinity of rays differently refrangible, and offering in their colours an imperceptible gradation of shades bearing relation to seven principal species. The results of experiments made by the aid of the prism will lead to the explication given by the celebrated English geometer, of the manner in which the rainbow is formed, to the consequences which he has deduced from the phenomenon of coloured rings with respect to the natural colours of various substances, and to the difference between transparent and opaque bodies.

From thence we shall pass to the phenomena of vision; and after having described the structure of the eye, shall first consider that organ in circumstances where under the guidance of the touch it acquires an exercise which may become the foundation of rules from which we judge of the form, the magnitude, and the distance of objects. We shall afterwards explain how the defect of some one of the conditions implied in the same rules draws the eye into those errors which have been called *optical illusions;* among which two of the most remarkable are, that which induces us to suppose the moon is much greater in the horizon than at the meridian, and that whence springs the apparent derangement of the stars, known under the name of aberration.

To the effects of natural vision will succeed those of vision assisted by art. The laws of reflexion will enable us to conceive how the images of objects, such as those presented by mirrors, are produced; whether those which, having a plane surface, depict those images faithfully, or those which, being concave or convex, cause a variation in the forms, magnitudes, and distances. We shall next contemplate the effects of refracted light, with regard to vision; and first supposing a refringent medium having a plane surface, and a radiant point placed in its interior, we shall treat of the question relative to the determination of the imaginary point of concourse of rays, which, after proceeding from the radiant point, are dispersed by the effect of refraction on passing into a different medium. After having applied the same theory to the vision of objects situated in water, we shall describe a very remarkable phenomenon depending on the property possessed by certain substances of doubling the images of objects seen through two of their faces taken on two opposite sides; and we shall attempt to throw some light on the theory of this phenomenon, by considering in carbonate of lime that of all the substances in which it is required to reconcile better with observation the divers circumstances that modify them.

We shall then develope the effects of simple glasses, which, by means of their curvature, assist our sight, or remedy its imperfections. The theory of these effects will lead us to explain those of instruments which result from the combination of several glasses, such as telescopes and microscopes; and to make the resources known which art has derived from refraction, whether employed solely or when combined with reflexion, in magnifying objects, drawing them nearer, and shewing to us those whose existence would be otherwise unknown. We shall especially endeavour to present with perspicuity the principle on which the construction of achromatic telescopes is founded, retarded for a long time by the obstacle which was opposed to it in the authority of Newton, first announced as possible by Euler, and undertaken with much success by Dollond. Finally, that nothing may be omitted which will be interesting in a subject so varied, we shall give a succinct description of instruments, such as the camera obscura, and the solar microscope, which produce their effects on a plane duly presented as a ground to intercept the pencil of light.

In what we have borrowed from chemistry we have limited ourselves to that which was necessary, in order to understand the physical phenomena which partly depend on affinity or some other analogous force. Besides, we could so much the rather be excused from descanting on the branches of knowledge relative to the actions of these forces, since France is beholden to the labours of Chaptal[*], Fourcroy[†], and Bertholet[‡], for many justly celebrated performances, in which these topics, and all others embraced by the same science, have been developed in such a manner, that nothing else need be desired.

Our design in composing this work has been, to present an accurate and rational Treatise of Natural Philosophy. We have cited only a small number of experiments, chosen from among the most decisive, and we have given to the consequences deducible from them, all the developement consistent with our purpose. An explication becomes vague when it is reduced to that which has farther generality. Details are, so to speak, the touchstone of theories; either they guarantee their justness, or they detect their incorrectness. They put it in our power to follow, step by step, the progress of nature; they enable us to understand all the relations which establish the mutual dependance of facts, either one with another, or with the fact that serves as the basis of the theory. They generate those distinct ideas which perfect and polish, so to speak, the conception of a phenomenon. These developements have, moreover, this advantage, that they fill up the vacuities perceived by those who

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[*] Elémens de Chimie. These have been translated by Nicholson.

[†] Elémens d'Histoire Naturelle et de Chimie. Systême des Connoissances Chimiques. Translated, the former by Heron and by Nicholson, the latter by Nicholson.

[‡] Essai de Statique Chimique. Translated by Lambert.

would go to the bottom of things, and obviate those questions which would leave the mind in a state of darkness.

In adopting this method of treating a subject which has such numerous and frequently such delicate ramifications, and which expands itself so as to comprise scientific topics quite modern, and as yet but little known, we have felt the necessity of consulting others; and we conceive ourselves bound to express our acknowledgement here, that we have gained much from the discourses of the celebrated Laplace. It is known, that in the midst of his sublime investigations relative to physical astronomy, he has discovered the secret of acquiring, in the different branches of knowledge, a superiority rarely attained even by those who cultivate only one.

In attempting to present, by the assistance of simple reasoning, the spirit of the geometrical methods employed to demonstrate the truths which we propose to develope, we thought a complete exposition of the methods themselves might be dispensed with: we have merely placed in notes some results not to be found elsewhere; and we cannot but be sensible with what pleasure those will be read which relate to Electricity, and which we obtained from our learned brother Biot, who, by permitting us to publish them, has furnished a new token of the interest which he is pleased to take in our labours.

AN

ELEMENTARY TREATISE

OF

NATURAL PHILOSOPHY.

1. NATURAL PHILOSOPHY proposes for its object the knowledge of the phenomena of nature. In the production of these phenomena bodies manifest various properties, the study of which must particularly excite our attention; and it is in investigating the laws established by the Supreme Being, to regulate the exercise of these properties, that we rise to the invention of theories which serve to connect the facts one to another, and to shew us their mutual dependance.

I. ON THE MOST GENERAL PROPERTIES OF BODIES.

2. Among the different properties of which bodies are possessed, the first that present themselves to our observation are those that are most intimately attached to the very nature of those beings considered as simple assemblages of material particles. These may be re-

duced to the three following: Extension, Impenetrability, and Divisibility.

3. Some philosophers have exhausted themselves in tedious discussions, in order to ascertain what is the true notion of extension, and whether it constitutes the essence of matter. We know not enough of the nature of bodies to decide this sort of questions, and the true philosophers of the present age do not employ themselves about them. Satisfied of this, that they can learn something of extension as it respects the senses, they conceive that there is extension, especially where there is contiguity and distinction of parts; and that which is interesting to them is to be able to measure extension, instead of amusing themselves with defining it: this is effected by comparing the different parts, and deducing from that comparison results truly useful in the progress of our knowledge.

1. *Of Extension.*

4. The manner in which the extension of a body is bounded in every direction, determines the figure of that body; and it may be said that the figures of bodies admit of an infinite variety, considering the matter generally, and re-uniting all the shades that may be presented by the portrait of nature. But these shades only modify, more or less slightly, the striking and prominent resemblances which otherwise exist between the beings of each species, whether among animals and vegetables, or even among a great number of inorganic bodies, enclosed within the bowels of the earth: now fixing our attention principally on these latter, the consideration of which, under a certain point of view, falls within the jurisdiction of natural philosophy, it may be remarked, that many of these bodies will present regular and determinate figures, such that their

aspect announces, at once, the action of a cause subject to certain laws which have their measure and their limits. These bodies are called *crystals*, and have a considerable analogy with the solids contemplated by geometers: thus in minerals, the character of perfection is attached to the right line; the rounded forms are owing to a species of perturbation, which are proofs that some forces formerly solicited the moleculæ mutually to unite; while in animals and vegetables, the contours and the softened curvilinear boundaries appertain to the organisation itself, and largely contribute to the grace and elegance of their shapes.

5. Philosophers have concluded from these observations, that crystalised bodies are themselves composed of particles of a determinate figure, and several of them have had recourse to the microscope, with a view of extorting from nature the secret of elementary forms, calling in the assistance of this instrument to trace the origin of crystals. But in this case the microscope reveals nothing beyond what may be discovered by the unassisted eye; the smallest bodies we can perceive by their aid are crystals only in part formed, and these merely differ in their dimensions from those whose augmentation has arrived at its limit. We shall explain, farther on, the only means that appear susceptible of guiding us in researches of this kind, and shall propose in that which is subjected to our observations indices which, if not certain, are at least probable, of the forms assumed by those indefinitely small parts of nature which always escape our view.

6. The extension of a body, considered relatively to the magnitude of its dimensions, gives the volume of that body: it is equivalent to that which mathematicians call *solidity*.

Hitherto we have only contemplated the surface, or the cover (if we may so speak) which envelops bodies.

We shall now proceed to shew what are the properties which result from the material parts comprehended under that cover.

7. If there were no vacuities in bodies, the proper quantity of matter of different bodies would be proportional to their volume; but it is known, that the interior of bodies is pierced with an infinity of minute vacuities, to which have been given the name of *pores;* and indeed it is very probable, that there is in bodies much more of void than of occupied space. The sum total of the material particles of a body is called its *mass;* and the sum of the material particles comprised under a given volume, assumed for a unit of measure, (as a cubic foot, a cubic inch, &c.) is called the *density* of the body: whence it results, that the density is the ratio of the mass to the volume, or, which amounts to the same, it may be represented by the quotient of the mass divided by the volume. Thus, for example, a piece of wood may have a greater mass than a piece of gold; provided its volume sufficiently exceeds that of the gold: but the wood is, necessarily, of less density than the gold, because it contains, under a given volume, much fewer material particles.

8. The faculty possessed by all bodies, of contracting during the process of cooling, as we shall explain in the sequel, shews that their moleculæ leave little interstices between them, which are permitted to approach one another: but even when we suppose the refrigerating process carried to its extreme, it does not follow, that the moleculæ will be entirely free from little separating spaces; since there may be in their form, their arrangement, and other circumstances, a cause of separation appertaining to the intimate nature of bodies. Hence we see that the expression of *immediate contact,* so frequently employed when speaking of the moleculæ of bodies, cannot be taken literally;

it solely denotes the smallest respective distance to which the particles can approach, with regard to the circumstances under which they are found.

Philosophers demonstrate the porosity of bodies by the aid of several well-known experiments. Produce a vacuum by means of an air-pump in a glass tube, terminated at its upper part by a wooden cup, whose bottom is 7 or 8 millimetres (about $\frac{1}{4}$ of an inch) in thickness, and fill the cup with water: this liquid will pass through the pores of the bottom of the cup, and fall in drops within the tube. Substituting for this latter another tube, furnished at top with a phial or bottle of crystal, to which a piece of ox-leather serves as a bottom, and which is filled with mercury to the height of two inches: on the first strokes of the piston the mercury will be perceived falling into the tube, under the form of a silver shower.

9. The same property may be demonstrated by means of a simple and interesting experiment made upon a stone, of which Newton has spoken, as possessing this same property, since it gives rise to a particular phenomenon of light*.

This stone is of the kind named *agates*, which are semi-transparent, and sufficiently hard to emit sparks at the stroke of a piece of steel: it has received the name of *hydrophanous* agate. When this is plunged into water, numerous series of little air-bubbles are seen to rise from its surface, succeeding each other without interruption. This air, which previously occupied the pores of the stone, is dislodged by the water which supplies its place: at the same time the stone acquires a new degree of transparency; and if we weigh it before the experiment, and again after the experiment, we shall find that its weight is augmented by a sensible quantity. We shall explain the physical

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* Optice Lucis, pars tertia, propos. tertia.

cause of the transparency of the hydrophanous agate, when we come to speak of the phenomena of light: we merely consider it here as offering a remarkable example of the porosity of bodies; and even the experiment we have just cited shews us more than we can learn from the ordinary experiments, namely, that we ought not to consider the pores as being absolutely void of all foreign matter, but rather as being occupied by air, or some other subtile fluid, disseminated between the moleculæ of bodies.

An hydrophanous agate, weighing about 18 decigrammes in its ordinary state, after having been subjected to this experiment weighed very nearly 21 decigrammes: whence it follows, that its weight was augmented by its sixth part. The stone loses, by the drying up of the water which it had imbibed, and recovers at the same time its natural opacity.

10. The skin of man and of animals is pierced with an infinitude of pores, through which, by means of the transpiration, the parts of the aliments escape which do not contribute to nourishment. Independently of the sensible perspiration, which is called *sweat*, and which is accidental, there is, moreover, one that is insensible, acting more or less at every instant, and which none could conceive to be so abundant as it is, before the experiments of Sanctorius. This celebrated philosopher has had the resolution to pass a part of his life in a balance, wherein he weighed himself, in order to determine the loss occasioned by the effects of the insensible perspiration. He has found that this kind of evacuation causes us to lose, in the space of twenty-four hours, about $\frac{5}{8}$ of the nutriment which we have taken.

Dodard, in repeating afterwards the same experiments, has had regard to the difference of age, and is convinced that a person perspires much the most in his youth. But the philosophers who have directed their attention to this object have not sufficiently distinguished the effect of the perspiration or transpiration which is performed by the lungs, and of which the matter escapes by expiration, from the effect which is attributable to the cutaneous perspiration, or to that which obtains through the intermediation of the skin. Seguin has undertaken, in conjunction with Lavoisier, to determine these two effects separately; and after having sought, in the usual manner, the total result of the transpiration, has suppressed that which is performed by the skin, by applying upon that organ a cover impermeable to the humour which it transmits outwardly: thus has been obtained the quantity of the pulmonary transpiration: and the mean between the results of these experiments gives $\frac{7}{11}$ for the ratio between this quantity and that of the cutaneous perspiration—that is, the effect produced by the pulmonary transpiration is more than the third of the total effect (*a*).

(*a*) As M. Haüy has not mentioned any of the researches which have been made into this interesting subject by British philosophers, the translator was solicitous to supply this deficiency; and has been enabled to-accomplish it by the kind loan of some able performances from the library of an eminent physician, whose extensive knowledge and professional skill can only be equalled by his urbanity and readiness to oblige.

Besides some remarks on this topic, incidentally thrown out among Dr. Adair Crawford's valuable " Experiments and Observations on Animal Heat," those who wish to acquaint themselves with the ablest dissertations relative to it, would do well to consult Dr. Lining's " Account of Statical Experiments, made on himself, several times in a day for one whole year," in vol. xlii. of the Phil. Trans. (New Abridg. vol. viii.); " Dissertatio medica inauguralis, de Perspiratione Insensibili—Jac. Hamilton," in Thesaurus Medicus, vol. iii.; " An Essay on the Functions of the Skin," being the third of Mr. Abernethy's Surgical and Philosophical Essays; and " Experiments on the Insensible Perspiration of the Human Body, shewing its Affinity to Respiration," by Mr. W. Cruikshank, late Professor of Chemistry at Woolwich.

Sanctorius, in a series of experiments, weighed himself daily for 30 years, with a view to determine the quantity of the insensible perspiration; but did not take into his calculation the insensible absorption from the atmosphere; and might, therefore, frequently be attributing that to checked perspiration which belonged to insensible absorption. He appears also to have allowed too

11. We have not any means of estimating the absolute density of bodies. It would be necessary for this that there should exist a perfectly dense matter, which might serve for a term of comparison, to ascertain with respect to every body, the ratio between the proper quantity of matter and the sum of the pores. Through the want of such a substance, we can only compare with one another the different densities of bodies; and

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little out of eight pounds of food, for the loss by urine and the intestinal discharge. Though, after all, it is probable his determination of the insensible perspiration was too low.

Boerhaave remarked that, by thrusting the naked arm into a long narrow glass vessel, the insensible perspiration becomes sensible, in the same way that the vapour of the lungs becomes sensible by winter's cold, or breathing on a mirror. And Winslow says, he could demonstrate the visible perspiration, by opposing his naked head to a white wall, in a fine summer's day, as the vapour would then appear visible, and ascend like smoke.

Tachenius collected four ounces of water in bed, by previously oiling his sheets; an experiment exactly similar to that of sleeping in sheets of oiled silk. "*Olim Tachenius* (says Haller) *sub tela olea tincta ad quatuor aquæ uncias collegit.*" The idea was ingenious; but, as Mr. Cruikshank remarks, "the error here was, that the absorbents of the skin were drinking up the condensed vapour, perhaps almost as fast as it was thrown out by the vessels of perspiration."

Mr. Abernethy proposes the distinctive appellations of aqueous and aeriform perspiration, instead of sensible and insensible perspiration. This gentleman concludes, from his experiments: 1st. That the remainder of the perspired air, after the separation of the carbonic gas (fixed air, which, he thinks, constitutes full two-thirds of the whole), is nitrogeneous gas (phlogisticated air). 2dly. That the quantity cannot be well estimated. 3dly. That when, by exercise, aqueous perspiration was increased, less air was produced; if the same vessels secrete both these fluids, this observation would naturally be expected. When the circulation is moderately carried on, insensible or aeriform perspiration is chiefly continued; but when the determination of blood to the surface is rapid and powerful, water is poured forth from the exhalents, and the perspiration becomes sensible. The experiments, he says, are decisive as to the *quality*, though not entirely so as to the *quantity* of the matter exhaled from the skin. In three experiments, however, the least quantity of carbonic gas emitted from the hand, in one hour, was three drams by measure; it being supposed that the heat of the weather increased the secretion from the skin, he considers two drams as the ordinary quantity. If, then, the perspiration of all parts were equal, seventy-seven dram measures of carbonic gas, and one-third of that quantity of nitrogeneous gas, would be emitted from the body in the space of one hour: and if perspiration be supposed at all times of the day nearly equal, about three gallons of air would be thrown out from the body in the course of one day. Although the quantity of air perspired is so large, yet Mr.

this is accomplished by the assistance of weights, as we shall explain speedily.

2. *Impenetrability.*

12. By *impenetrability* is meant the faculty which a body has of excluding every other body from the place that it occupies, in such manner, that two bodies placed in contact can never occupy less space than that which they filled when they were separate. The impenetra-

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Abernethy concludes, that the weight of the body will not be much altered by its loss—it being the aqueous perspiration by which that will be principally diminished.

Mr. Cruikshank judiciously observes, that the size of the body, the quantity of food taken in, the vigour with which the system is acting, the passions of the mind, and external heat or cold, are circumstances which will ever occasion considerable variety in the quantity of the insensible perspiration. This gentleman, assuming that the surface of the hand is to that of the rest of the body as one to sixty (an assumption which Mr. Abernethy thinks much too small for the body), and that every part of that surface perspired equally with his hand, concluded that he lost during an hour, by insensible perspiration from the skin, 3 ounces 6 drams; and in 24 hours, at that rate, would have lost 7 pounds six ounces. Also, that he lost 124 grains of vapour by respiration, in an hour; or 6 ounces, 1 dram, and 36 grains, in 24 hours; which, added to the former cutaneous exhalation, would make the whole insensible perspiration, in 24 hours, equal to 8 pounds, 1 dram, and 36 grains: the evaporation from the lungs will be little more than one-fifteenth of the whole. This result is, as the reader will perceive, widely different from that of Sequin, mentioned by M. Haüy.

Mr. Cruikshank has not the smallest doubt, but that *electric fluid* is also perspired from the pores of the skin: it appearing to him impossible that an enraged lion, or cat, should erect the hairs of the tail on any other principle: indeed he strongly suspects that, as electric fire is now known to be the prime conductor of the variation in the atmosphere, so it is also the grand conductor of insensible perspiration. He likewise states it as a matter beyond doubt, that, independent of aqueous vapour (of fixed air and phlogiston) emitted from the skin in insensible perspiration, there is an odorous effluvia, which, though generally insensible to ourselves and the bye-standers, is perceptible to other animals: this is remarkable in the parts of generation, arm-pits, and groins. Hence it happens, that a dog follows the footsteps of his master by the smell; and, in like manner, with regard to other animals: the fox-hound knows *afar* the smell of the fox; the pointer that of the partridge, the snipe, or the pheasant; and every carnivorous animal that of its prey.—Tr.

bility of solid bodies does not require to be proved—it strikes us at first view; but fluids, having their moleculæ perfectly moveable in every direction, and yielding to the slightest pressure, their impenetrability does not manifest itself so perceptibly as that of solid bodies. Taking the air for an example: so long as this fluid is not enclosed in something, its extreme mobility causes it to admit a free passage to all bodies which are moved through it; but in this case it is properly displaced, and not penetrated; for, if the air be included within the sides of a vessel, and another body be then presented to take its place, without suffering it to escape, it will exercise its impenetrability in the same manner as solid bodies. It is easy to be convinced of this by the aid of a very simple experiment, which any one may make: it consists in plunging a vessel vertically, with the orifice downwards, in another vessel filled with water to a certain height: the surface of the water corresponding with the orifice of the first vessel, is depressed as this vessel itself descends; and this depression may be rendered more sensible by means of a little plate or slip of cork, placed so as to float upon the surface of the water: nevertheless this water is not excluded by the air occupying the immersed vessel; it is always raised within it by a certain quantity, which augments as the vessel is immersed to a greater depth: but it is sufficiently evident, that this ascension is occasioned by the circumstance that the air is a compressible fluid, and therefore its volume is contracted into a smaller space, by the effect of the compression exerted upon it by the surrounding water on all parts, in virtue of its weight.

We must here notice a difficulty which appears to result from this, that when we have mingled certain bodies, the volume of the mixture is less than the sum of the volumes taken separately. This happens, for example, when we mix equal parts of *alcohol* and *water*;

the same also obtains when we mingle by fusion *copper* with *zinc*, in order to form the compound metal called *brass:* it is then observed, that the density of the mixture is augmented by about its tenth part. This apparent penetration is owing to the circumstance, that the moleculæ of the two bodies, in consequence of their respective formation, generally approach one another more than in the two bodies taken separately: there hence results, in the figure of the pores, such a change as diminishes the space equal to the sum of these pores. On the contrary, in the alloy of *silver* with copper, a kind of rarefaction is produced, such that the volume of the mixture is a little greater than the sum of the volumes of the two bodies, previous to fusion.

3. *Divisibility.*

13. The word *divisibility*, restrained to its simple signification, presents no idea that is not perfectly known, since all bodies have parts which are readily conceived to be separable, the one from the other. But is matter itself really divisible to infinity, so that its division does not admit of any possible limits? or rather, is it constituted, in the ultimate result, of indivisible moleculæ that must be regarded as simple? Here springs a new source of interminable discussions between the partizans of the two opinions, wherein the human mind has exercised all its subtilty to find arguments in favour of each, and to oppose difficulties to the other: after having disputed much, and written much, all on the subject of an atom, it is not at all advanced; and indeed the solution of the question itself would not give one step to the progress of science. Let us banish from natural philosophy all questions so unfruitful, as they respect the progress of our

knowledge. Instead of enquiring whether bodies admit of infinite division, we would analyse them, as far as is consistent with our own powers; and would deduce from the analyses such knowledge, as will diffuse light over facts previously regarded as inexplicable. It has been wisely remarked, that the bounds of experience and of observation are, in relation to us, those of nature itself.

14. It is, however, certain with respect to the division of bodies, that in the result parts are separable the one from the other, the minuteness of which surpasses the imagination. In proof of this, we may first mention colouring substances, and particularly carmine, which is a kind of powder ohtained from the insect, commonly named *cochineal*. Dilute a small quantity of this powder, to the weight of five centigrammes (or about ¾ of a grain), by putting it at the bottom of a vessel, in which is afterwards poured 15 kilogrammes, or nearly 30 pounds, of water: the colour will be so diffused, as to be perceptible throughout the whole volume of the water. The weight of this water being three hundred thousand times greater than that of five centigrammes of carmine, if it be supposed that each centigramme of the fluid mixture contains only two moleculæ of the colouring princiciple, there will be three millions of visible parts in five centigrammes of carmine.

The impressions made upon the sense of smelling are not less proper than those which affect the sight, in assisting to judge of the extreme divisibility of which matter is susceptible. There are bodies whose weight is scarcely sensibly altered after a long interval of time, during which, all those who are found within a certain distance incessantly experience the action of the odoriferous particles emanated from the substance of these bodies.

There is taken from a bag, contained in the bodies of certain animals, a substance, to which has been given the name of *musk*, and of which a single grain will send forth a strong odour, during a certain number of years, in an apartment into which fresh air is frequently admitted. The simple friction of a paper, in which a small portion of the same substance has been wrapped, will suffice to make a habit impart a fragrant smell for several days.

15. Some operations in the arts will furnish a much more just idea of the same property, because their results are susceptible of being reduced to calculation. According to the observations of Boyle, the weight of a grain of gold, or about 53 milligrammes, reduced to leaves, will cover a surface of 50 square inches; each of which will, of consequence, measure nearly 27 millimetres across; but, we may conceive the millimetre (about $\frac{1}{23}$ of an inch) divided into eight visible parts; this will give 46656 little visible squares in a square leaf of gold, each side of which measured 27 millimetres; and, as the number of these leaves is 50, we may conclude that a small mass of gold, weighing only a grain, may be divided into more than two millions of parts, each perceptible to the simple sight; but, by means of a microscope, each of these parts would become as it were a leaf of gold, where the eye and the computation would still find subjects for their exercise.

This division proceeds much farther still, in the labour of wire-drawing gold. Take a certain quantity of leaf gold, in weight not exceeding three decigrammes, or about an ounce, and cover with it a cylinder of silver. Cause this covered cylinder to pass successively through several holes in a wire-drawing iron; and, when it is reduced to a thread as delicate as a hair, it will be covered on all its points by an extremely thin coat of gold; then let the wire be flattened between two steel rollers. In this state it will form a plate, in length nearly equal to 444000 metres, answering to 111 leagues, each of 2000 toises. But this plate being clothed with a covering of gold on each of its faces, may be considered as two plates of gold of an extreme tenuity, and placed mentally one at the end of the other. Moreover, the breadth of the lamina being about $\frac{1}{4}$ of a millimetre, or $\frac{1}{9}$ of a line, we may suppose this breadth divided into two, and thus the quantity of gold employed is equivalent to four plates, the length of each of which is about 444000 metres. Now if it be imagined, that each of the millimetres comprised in this length is divided into eight parts, we shall have more than 14 billions of visible parts, in a mass of gold weighing only an ounce, and which is equivalent to a cube of gold whose side is not more than 12 millimetres, or $5\frac{1}{5}$ lines, in length.

This prodigious extension of which gold is susceptible depends upon its ductility, combined with its great density; two qualities equally precious for those arts whose object is to apply this metal upon the surface of wood, copper, and other substances, where it serves at once both for security and for ornament.

16. We shall add another example, drawn from the stony substance known by the name of *mica*, and which yields, with great facility, to the operation called *mechanical division*. We have succeeded in detaching, from the original piece, a plate which, instead of the yellowish colour natural to the stone, reflected a fine blue, which, as we shall explain when treating of light, indicated an extreme degree of tenuity. Having calculated the thickness of this plate, after a rule marked out by Newton, and which we shall then also make known, we found it equal to 43-millionths of a millimetre, or about 1·6-millionth of an inch;

hence it follows, that we might obtain 23255 isolated plates, by dividing a piece of mica of the thickness of a millimetre, or $\frac{4}{9}$ of a line.

17. We cannot better terminate this article than by exhibiting a very judicious notion entertained by Newton, relative to the limits prescribed to the division of bodies in the actual state of things. This great philosopher conceives that the Supreme Being, in creating matter, formed it of various species of elementary moleculæ, solid, hard, unchangeable, the figures and the different qualities of which were appropriated to the respective ends they were proposed to answer.* But such is the fixity of these moleculæ, that no process of art, nor even any force existing in nature, can either divide or alter them, unless the essence of the body should be changed with time. Thus all the modifications experienced by bodies depend solely upon this, that these durable moleculæ separate the one from the other, and then become reunited, in various ways forming new combinations. These different moleculæ are, hence, the simple substances of chemistry; and the results of the operations which they would present singly, should be the design of the efforts of this science; in the mean time we may consider as simple the substances which we have not yet been able to decompose, and wisely imagine simplicity to reside at the place where observation stops.

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* Optice Lucis. lib. iii, quæst. 31.

II. PROPERTIES RELATIVE TO CERTAIN FORCES SOLICITING OR IMPELLING BODIES.

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1. *Mobility.*

18. Mobility is the faculty possessed by a body, of being capable of transportation from one place to another. That state which is called *motion*, supposes the action of a cause, to which has been given the name of *force*, or of *power*. That this cause may exist, it is not necessary that the bodies which it solicits should be in actual motion. Thus, when two bodies make an equilibrium, at the extremities of the arms of a balance, they are maintained in that state by forces really existing, but whose effects mutually destroy each other, so as to prevent the production in either body of any tendency to move.

19. Motion is uniform when the moving body always describes the same space in the same time; it is accelerated or retarded when the moveable describes, in equal times, spaces which are successively augmenting or diminishing (*b*).

Velocity.

20. In uniform motion, the time employed in describing any determinate space may be more or less

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(*b*) When the velocity is always equally augmented in equal times, the motion is called *uniformly accelerated:* when, on the contrary, it is always diminished by equal quantities, in equal times, the motion is said to be *uniformly retarded.*—Tr.

long, according to the greater or less energy of the moving force.

21. To compare respectively the motions of two bodies in the case of uniformity, we take an interval of time, the second for example, for a unit of time; in like manner we choose a unit of space, such as the metre, the yard, or the foot: thus we can express the total space described by a body, and the time of description, by abstract numbers, each indicating how often it contains the unit of its respective kind; and by dividing the number representing the space by that which represents the time, we shall have an expression for the velocity of each body. If it be supposed, for instance, that one of the bodies has run over 35 metres in 7 seconds, and the other 24 metres in 6 seconds, the velocity of the first will be denoted by $\frac{35}{7}$, and that of the second by $\frac{24}{6}$; that is to say, the velocities will be respectively in the ratio of 5 to 4.

Hence we may see in what sense we must take the notion which has been given to velocity, when we say that it is equal to the quotient of the space divided by the time. Speaking rigorously, we cannot divide two heterogeneous quantities, such as space and time, the one by the other: but the language now in question is no other than an abridged manner of expressing that the velocity is equal to the number of units of space divided by the number of units of time, which measure the motion of a body (*c*).

22. As forces only manifest themselves to our notice

(*c*) In variable motions, the velocity undergoing repeated changes, it is usual to estimate it at any time whatever, by the space it is capable of passing over during a unit of time, if its motion for that interval continued the same as at the instant where we would consider the velocity. Or, taking an indefinitely minute interval of time, we may call the velocity of a moving body, for that instant, the ratio of the infinitely little space described in that minute interval, to its duration, or rather the ultimate ratio of those two quantities.—Tr.

by their effects, it is only by the effects they are capable of producing that we can measure them; but, the effect of a force is to impress upon every particle of a body a certain velocity: let it be supposed in this case, that all the particles have received the same velocity, and the effect of the force has for its measure the velocity taken so often as there are particles in the body; or for abbreviation, we may say, its measure is the product of the mass by the velocity: this product is that which is called *the quantity of motion of a body.*

Inertia.

23. All bodies persevere or continue, as of themselves, in their state of rest or of uniform motion in a right line, in such manner, that a body at rest cannot move without being solicited or urged by some force; neither can the rectilinear and uniform motion of a body be changed without the action of a foreign cause.

It hence follows, that when a body proceeds with an accelerated or a retarded motion, we must suppose the action of a force operating, at every instant, to occasion a variation in the velocity which, independent of this, would be uniform.

24. What we are about to lay down is only a different manner of stating that a body cannot of itself enter into motion, neither can it of itself diminish the motion which it previously possessed. That want of aptitude which bodies have, of producing in themselves a change in their actual state, is called *inertia.* Now it is known that a body, whose state may be changed by the action of a foreign force, cannot give way to that effect, otherwise than by itself altering the state of that force; that is to say, by itself taking

away a part of its motion. It has hence been concluded, that the continuance of a body in its state of repose, or of uniform motion, was itself the effect of a real force which resided in that body; and this force has been viewed, sometimes as a resistance in so far as it opposed itself to the action of the other force, which changed the state of that body, and sometimes as an effort, in so far as it tended to carry with it the change in the state of the other force.

25. The celebrated Laplace has proposed a more precise and natural manner of contemplating inertia. To conceive in what it consists, suppose a body in motion to meet with a body at rest: it will communicate to it a part of its motion; in such manner, that if the first have, for example, a mass double to that of the second, in which case its mass will be two-thirds of the sum of the masses, the velocity which it will retain will be also two-thirds of that which it had at first; and as the other third which it has yielded to the second body employs itself upon a mass of only half the magnitude of the former, the two bodies will both have the same velocity after the shock. The effect of inertia is reduced, therefore, to the communication made by one of these bodies to the other, of a part of its motion; and since this latter cannot receive, but in consequence of the other's losing, this loss has been attributed to a resistance exercised by the body receiving the motion. But in the instance before us, it is very nearly as in the motion of an elastic fluid, contained in a vessel from which we would open a communication to another vessel which should be empty; this fluid would introduce itself by its expansive force into the second vessel, until it became uniformly distributed in the capacities of the two vessels: in like manner a body when it strikes another does nothing else, if we may so express ourselves, than pour into this latter a part of its motion; and there is no more reason to suppose a resistance in this case than in the examples we have just cited.

It is true that when we strike with the hand a body at rest, or whose motion is less rapid than that of the hand, we imagine that we experience a resistance; but the illusion proceeds from this that the effect is the same with regard to the hand, as though it were at rest, and was struck by the body with a motion in a contrary direction.

We limit ourselves here to these general notions relative to mobility; and shall not enter into details respecting different kinds of motion, and other results, the consideration of which properly belongs to the physico-mathematical sciences.

2. *Hardness.*

26. Hardness is the resistance opposed by a body to the separation of its moleculæ; this property depends on the force of cohesion, or on that which the chemists call *affinity*, joined to the arrangement of the moleculæ, to their figure and other circumstances. A body is considered more hard in proportion as it presents greater resistance to the friction of another hard body, such as a steel file, or as it is more capable of wearing or working into such other body to which it may itself be applied by friction. Lapidaries judge of the hardness of fine stones, and other such bodies as are the subject of their art, from the difficulty with which they are worn down or polished, when presented to the action of the grinder.

27. The diamond is the hardest of all known bodies. The little faces which are the source of the vivacity of its reflexions are the work of the diamond itself, and it is only by the aid of its own peculiar dust that we can cut and polish it.

28. We have spoken of friction or rubbing rather than percussion, as being in some sort a measure of the hardness of bodies, since the resistance which this latter

opposes to the first of these forces, does not always announce that which it is capable of opposing to the second. Thus glass, though harder than wood, yields more easily to percussion. Even the diamond may be divided by the effort of the hammer, at the same time that other bodies will remain whole. This faculty possessed by certain bodies of giving way in parts more or less to the effect of percussion, has been denoted by the name *fragility* or *brittleness*; whence it follows that we must not confound *brittle* bodies with *soft* ones, the latter only being in opposition to *hard* bodies. There is not, probably, a body whose fragility is more forcibly contrasted with its hardness, than a greenish, transparent stone, very sensibly lamellated, found in Peru, and to which the French have given the name of *euclase*. After that it has yielded, with much difficulty, to the efforts employed to polish it, it is surprising to see how easily it separates into splinters, by the effect of a very light pressure.

3. *Elasticity and Ductility.*

29. The action of one body upon another may be such as will not occasion an entire separation of the parts of the latter, but simply a displacing of its moleculæ, the effect of which is a variation of its figure, or even of its volume. We call in general *compressible*, bodies that are susceptible of a change of figure by the action of an extraneous cause; and the results of this species of action give rise to a new order of phenomena which are subdivided into two classes: in one class the body which has been subjected to the change has the property of returning of itself to its natural figure, where the cause which had deranged its parts ceases to act upon it. Thus a plate of steel which we bend, recovers its rectilinear posture as soon as it is abandoned to itself. This property

has been named *elasticity*, and those bodies are called *elastic* that are endowed with it. In the other class the body retains the new figure, which it has been compelled to assume. Thus the inflexion which a plate of lead has undergone, remains when nothing acts upon that plate. We shall proceed to furnish some details relative to these two classes of phenomena.

30. The return of elastic bodies to their natural form is not made suddenly, and by a single motion, in a direction contrary to that which produced the change of shape; but the moleculæ of these bodies perform vibrations, which transport them successively on this side and that side of their original positions, and which continually diminish until the moleculæ have all recovered those positions.

The vibrations of which we are now speaking especially exhibit themselves in a remarkable manner, in the strings of several musical instruments, as we shall explain when we treat of sound. They are likewise very apparent in a plate of steel, fixed by one extremity, and which after being curved by leaning on the opposite extremity, is permitted to play freely.

31. The stroke of a hard body produces analogous effects upon a globe of ivory, though they are performed with such a rapidity, as renders them unappreciable by our senses, so that even the change of figure which the globe undergoes cannot be perceived; but we may make it sensible by suffering the globe to fall upon a table of black marble well polished, and done over with a light coat of oil. Afterwards when we look at this table obliquely, we may see at the place of contact, a round spot, whose diameter is more or less considerable, according to the height from whence the globe has fallen. But it is evident that this body, had it retained its figure, could only touch the table by one point; and although the marble might, on its part, suffer a depression, and immediately re-establish itself, yet it is not to be doubted

that the globe itself contributes much more to the formation of the spot by its change of figure; so that this experiment presents a double proof of the effect we are considering.

32. We may now shew in what manner we must conceive the re-establishment of the figure which is performed in the globe by a gradation, imperceptible, and almost instantaneous: at the moment of the stroke, the parts nearest the contact are driven towards the centre, while the most distant parts advance by a contrary motion; whence it follows that the globe assumes a flattened form in the direction of its vertical axis, and becomes lengthened in the direction of its horizontal axis. When after this the unbending or rebounding commences, it makes a new change in the figure contrary to the former, so that the globe lengthens in the direction of the vertical axis; and these two changes of figure continue to succeed each other, going on by diminishing degrees, until the body has returned to the globular form which it had previous to the stroke.

It is in consequence of the unbending after the shock, that the globe after having struck the marble table, flies back and remounts towards the point whence it was let fall. When two elastic bodies strike each other, their unbending impresses upon them velocities in a contrary sense to the motion with which they were carried the one towards the other. Mathematicians have represented by formulæ, the relations of these velocities in the different cases to which the phenomenon extends.

33. There exist a certain number of bodies which are at the same time very hard and very elastic, so that the two qualities seem to have a great mutual relation. It is well known how far both may be augmented in steel, by the operation of tempering.

34. Elasticity, which varies between very extended limits in solid bodies, of which while several possess it to so high a degree, others appear to be destitute of it,

becomes, as to perception, nothing in all the liquid bodies, at least, if we judge by the resistance they oppose to compression, as will be observed when we treat of water: but the passage to the gaseous state shews, in all the bodies which have undergone that change, an elastic virtue so marked and so general, that they have received the name of *elastic fluids*. The moleculæ of these fluids are similar to so many little springs, which are compressed when any cause whatever tends to bind up or enclose a mass of one of these fluids in a smaller space than that which it previously occupied, and which afterwards return to their usual state when the compression ceases to have place, the mass of the fluid taking again, by dilating itself, the place which it had relinquished.

35. The major part of the philosophers who have attempted to give a theory of elasticity, have especially considered that when an elastic body is bent, for example to an arc, the particles situated on the convex side become farther separated from one another, while those which are on the concave side approach each other. But of all the causes on which the re-establishment of the body in its first state has been made to depend, such as attraction, the resistance of a particular subtile matter, diffused between the molecules of bodies, the action of caloric, &c. there is not any which is conducive to a satisfactory explanation of the phenomena.

36. It is to elasticity that we owe a great part of the services rendered us by iron when converted into steel, and employed in the arts: it is from this use that spiral springs, communicating motion to watches and other machines destined to furnish a measure of time, borrow their force. Here, however, the diminution in the force of the spring during the period of its unbending itself, becomes a cause of retardation, in relation to a motion the essence of which consists in its uniformity. To obviate this inconvenience, the fusee on which the chain drawn by the spring is enveloped has given to

it the form of a conic frustum (*d*), in which the relation between the diameters of the circles parallel to the bases is combined with the variations of the moving force. In the first moment when this force operates with all its intensity the part of the chain which it draws lies upon the narrowest spire of the fusee, and afterwards in proportion as the spring becomes feebler the spires to which the parts of the chain that is unfolding correspond are gradually enlarging. Thus, on one part, the arms of the lever on which the resistance of the wheel-work acts, remains the same, since it is nothing else than the radius of the fusee wheel, the motion of which is communicated by an intimate connection to the hands of the watch.—On the other part, the arms of the lever on which the power of the first mover is exerted, to the place where the chain abandons the fusee as it unwraps, is continually lengthening; in such manner that the moving power regains at each instant by this lengthening an advantage equivalent to the loss in its own intensity, and the whole proceeds as though the two arms of the lever were perfectly equal. The whole of mechanics is full of equally interesting and ingenious applications of the force of elasticity: it is by this the pieces are regulated which occasion, in the twinkling of an eye, the explosion of portable fire arms, the flexible plates which soften the motions of carriages, and render their use so commodious and pleasant, and the cords of different musical instru-

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(*d*) This must only be considered as a popular illustration. If the action of the spring diminished equally as the parallels to the base of a triangle do, the cone which is generated by the revolution of a triangle would be the precise figure required for the fusee: but the weakening of the spring is not in that proportion. According to the investigation of Varignon the figure of the fusee is the solid generated by an equilateral hyperbola revolving about one of its asymptotes; and this is the conclusion adopted by Martin and several other English authors. But this result depends upon an hypothesis which does not universally obtain. The best general investigation we recollect having seen is given by Bossut in his Mecanique: but it cannot be inserted here without a wide departure from the object of this part of the work.—Tr.

ments, whose vibrations combined with those of the air, diversify the delightful gratifications of the ear.

37. There are no bodies whose elasticity is perfect, and probably there are none which are entirely divested of this quality. But here, as with respect to a great number of other phenomena, we stop at the limit where a quantity ceases to be appreciable; and we regard as non-elastic bodies which after having been compressed and forced to change their figure, remain in that new state, or those which absolutely resist compression.

38. The name of *ductility* has been given to the facility possessed by the chief bodies, and particularly certain metals, of being flattened by pressure or by percussion, in such manner as to retain the figure which they have taken in virtue of one of these two forces. The moleculæ in this case so glide the one over the other that the points of contact, though displaced, still always remain at distances sufficiently small for the mutual adherence to continue.

39. On comparing the elasticity, ductility, and hardness, in the six best known metals, it is found that the order of the elasticities follows that of the hardnesses; and commencing with that which possesses these two qualities in the highest degrees, the following is the succession of these metals: *iron*, *copper*, *silver*, *gold*, *pewter*, and *lead*. The ductilities, relatively to the four first of these metals, follow a progress inverted with respect to the other properties; so that the order is this: *gold*, *silver*, *copper*, and *iron*. But *pewter* holds the fifth rank, and *lead* the sixth, with regard to all the three properties; these two metals being at the same time the most soft, the least elastic, and the least ductile. The defect of play between the moleculæ necessary to produce ductility may contribute equally to the great force of adherence which obtains in hard bodies, and to the facility with which that adherence may be completely broken in soft bodies.

40. There are some bodies which are ductile both in

heat and cold: of this number likewise are metals: some bodies, such as glass, acquire ductility by heat; others, such as clay, become ductile by the interposition of a liquid between their moleculæ.

41. Ductility, a quality so valuable in metals, when the intention is to extend and apply them upon the surface of bodies, as is the case especially with respect to gold the most ductile of all, becomes, on the contrary, an inconvenience when we would employ them in masses; and the works made with these metals, fashioned in their natural state would not have sufficient consistence, and would be subject to deformity, and to lose the finish which the hand of art had given them. This is remedied by mixing with the metal employed, another metal whose moleculæ interposed between those of the former, diminish the play or tendency to move, and unite them more strongly one to the other. By means of these mixtures artists can render metals more hard, or more sonorous; they can modify the properties to their will, and can transform them to other intermediate metals, the diversity of which is suited to that of our wants.

4. *Gravity.*

42. We have given the name of *gravity* to the force in virtue of which a body abandoned to itself falls towards the earth.

43. The ancient philosophers have conceived various systems with a view to elevate themselves to the cause of this phenomenon, so simple in the eyes of the vulgar, who find it quite natural that a body should fall when it is not sustained. Of all these systems the most ingenious and the most seducing was that of Descartes, who made the fall of bodies depend on the motion of the subtile matter that circulated about the earth in a vortex. All the parts of this vortex having a centrifugal force solicit-

ing them farther from the earth, would constrain other bodies to move downward, in a direction contrary to that of this force. But even supposing the existence of these vortices, which no person of the present times admits, the explication of Descartes has many insoluble difficulties opposed to it; one of which consists in this, that a body placed in the plane of a parallel to the equator ought to descend obliquely at the surface of the earth towards the point of the axis which should correspond to the centre of the parallel in question, instead of which the direction of gravity is throughout perpendicular to the surface itself. This system of Descartes has disappeared from the presence of the theory of *universal gravitation*, of which the name alone expresses the sublime effort by the aid of which the genius of NEWTON has caused the celestial motions, and the great phenomena of nature, to come under the dominion of gravity.

On the Difference between Gravity and Weight.

44. Gravity must be contemplated as acting equally at every instant on all the moleculæ of a body. It first results from this principle that the velocity impressed upon a falling body does not depend upon the mass of that body; it is, with respect to the aggregate of the moleculæ of a body, the same as it would be for each detached particle of the mass: whether this mass be greater or smaller it will merely follow that there will be more or fewer moleculæ urged on with the same velocity; but the common velocity will be neither augmented nor diminished. Nevertheless we do not see all bodies fall with the same velocity, and arrive in equal times at the surface of the earth, supposing them to depart from quiescence at the same altitude. We shall state the reason of this difference after we have established

the distinction existing between the gravity of a body, and that which is properly called the *weight* of such body. Gravity is measured by the velocity which it impresses upon each molecule of a body, and this velocity is independant of the number of moleculæ; but the weight of a body is measured by the effort which must be made to sustain that body, and to hinder it from falling (*e*). But this effort is so much the more considerable, as there are in bodies more moleculæ urged on with the same velocity: hence the weight is properly expressed by the product of the mass into its velocity, from which it follows that it varies in the same ratio as the mass, relatively to bodies which we weigh, because these bodies are considered as solicited unto equal velocities. It is now easy to conceive why, among bodies abandoned, those of greater mass fall more speedily from the same height, than those whose masses are less considerable. This difference arises from the resistance of the air, which is relatively greater as the mass of bodies is less: for if we suppose, by way of example, two balls of the same diameter, the one of lead, the other of cork, to commence their fall at the same time, these two balls presenting equal surfaces to the resistance of the air will thus have two equal resistances applied to two bodies incited with the same initial velocity; whence it follows that the resistance of the air takes from the cork ball which has the smallest quantity of motion a greater portion of velocity than that which will be lost in the same time by the leaden ball; and the former, continuing to lose at

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(*e*) We may also distinguish, though the distinction is more verbal than philosophical, between *Weight* and *Heaviness*. Thus *heaviness* is that quality in a body which we feel and distinguish by itself: *weight* is the measure and degree of that quality, which we ascertain by comparison. Absolutely and in an undetermined sense, we say that a thing is *heavy*; but relatively, and in a manner determined, that it is of such a *weight*, as of 2, 3, 4, pounds, &c. Many circumstances prove the *heaviness* of atmospheric air; but the mercury in a barometer determines its exact *weight*. See Girard and Trusler on Synonymes.—Tr.

every instant more than the latter, will be always found more retarded.

45. Galileo, to whom was reserved the glory of preparing, long before, the way for the theory of Newton, by the discovery of the law to which the acceleration of heavy bodies is subjected, having let fall from a great height different balls of *gold*, of *lead*, of *copper*, of *porphyry*, with a ball of wax, observed that all these bodies employed nearly the same time in falling to the earth. The ball of *wax*, the only one which was sensibly retarded, was no more than 4 inches from the earth at the end of the fall of the other bodies. Galileo, considering that this difference was very far from being proportional to that of the weights, concluded that it depended solely on the resistance of the air. This conjecture has been since verified by direct experiments, consisting in letting fall from the top of a tube, within which the vacuum has been made the most perfect possible, bodies of different materials, such as lead, iron, wood, cork, feathers, wool, &c. and it has been found that none of these bodies will then permit of our perceiving any sensible difference in the duration of their fall. As to bodies which raise themselves in air, such as smoke, it is known that their ascension is occasioned by the circumstance of their being specifically lighter than air: they are, with respect to this fluid, situated as a piece of cork is with respect to water, which when immersed in that water to a certain depth, and then left to itself, rises again to the surface. The vulgar regard all as being without gravity which rises instead of falling: whence Newton remarked that the weight of the vulgar was the excess of the absolute weight of a body above the weight of the air. The ascent of air-balloons in the midst of the air is well calculated to undeceive the partisans of this theory of bodies without heaviness.

The Acceleration of Motion produced by Gravity.

We have seen (23) that a body when once put in motion tends of itself to persevere with the same velocity, and according to the same direction as it had at the first instant. But if the body be moved by a force which acts upon it without interruption, and the actions of which are equal during equal times, its velocity will increase continually and in a uniform manner.

47. Of this kind is the motion produced by gravity in the bodies which it solicits. To conceive clearly the law of acceleration which results, suppose that a body has employed a finite time, as three or four seconds, in falling from a certain height; we may consider this time as composed of an infinitude of indefinitely small instants, and it may be imagined that in the first instant the moveable receives from gravity a degree of velocity infinitely small, and that in each of the following instants an equal degree of velocity is added to the preceding velocity; so that the velocities of the moveable during the several consecutive instants of its fall will increase as the natural numbers 1, 2, 3, 4, 5, &c. It hence follows that the number of degrees of velocity acquired successively by the moveable, is always equal to the number of instants during which the motion has continued, that is to say, the velocity increases as the time.

Suppose that a right angled triangle $s\,c\,b$ (pl. I. fig. 1) is divided by the lines $g\,h$, $i\,l$, $k\,n$, &c. parallel to the base $b\,c$, in such manner that the parts $s\,h$, $h\,l$, $l\,n$, &c. of the height, comprised between these lines, are respectively equal: if it be conceived that these parts represent for example, seconds of time, $g\,h$ may represent the velocity acquired by the moveable at the end of the first second, $i\,l$ will denote the velocity acquired after two seconds, and so on throughout; for the lines $g\,h$, $i\,l$, $k\,n$, being respectively in the ratio of the lines *s h*, *s l*, *s n*, the former will be to the latter, as are the velocities in regard to the times.

If we now suppose the triangle *s c b* subdivided by an infinity of other lines comprised between *s* and *g h*, *g h* and *i l*, *i l* and *k n*, &c. these lines estimating from the point *s* will represent the velocities during the successive indefinitely small instants composing the times represented by *s h*, *s l*, *s n*, &c.; and since these velocities are nothing else than the minute spaces run over during the corresponding instants, the triangle *s g h* being the sum of the spaces which answer to the time measured by *s h*, that sum will represent the total space described during the first second: in like manner, the triangle *s i l* will represent the space run over during the two first seconds, and thus of others. But the triangles *s g h*, *s i l*, &c., are respectively as the squares of their altitudes *s h*, *s l*, &c.; whence we may conclude that the spaces described by the moveable from the commencement of its motion, are as the squares of the times employed in the description. Thus the times represented by *s h*, *s l*, *s n*, &c., being to one another in the proportion of the natural numbers 1, 2, 3, 4, 5, &c., the corresponding spaces will be in the proportion of the squares 1, 4, 9, 16, 25, &c., of those numbers.

Hence it is easy to establish the relation to which the spaces run over during different consecutive times respectively equal conform; for if we denote the first of these spaces by unity, it is very obvious that the succeeding ones will be represented by the difference between the terms of the series 1, 4, 9, 16, 25, &c., denoting the spaces from the origin of the motion. Therefore the spaces described during equal and consecutive times, estimating from that same origin, will be respectively as the odd numbers 1, 3, 5, 7, &c., among which all those that follow the first give the differences in question.

It has been found, by experiments, that a body to which the air does not oppose a sensible resistance would fall 15 feet $\frac{1}{10}$ (Paris measure), which answer nearly to 49 decimetres, in the first second of its motion (*f*). This knowledge once acquired, it is easy to determine the height through which a heavy body has fallen during a given number of seconds, by taking so many times 49 decimetres (for Paris, or so many times 16$\frac{1}{12}$ English feet for London) as there are units in the square of the number of seconds.

48. If we imagine that at the end of a certain time, that for example which is represented by *s h* (fig. 1.) the gravity, or the accelerating force, ceases to act; the body will then persevere in its motion by reason of the velocity *g h* becoming uniform. If therefore it be supposed to continue its motion for a time equal to the former, and that we may denote it by *h l*, the space which it would describe being equal to the velocity *g h* taken so often as there are instants comprised in *h l*, that space will be as the product of *g h* by *h l*, and such product is double the surface of the triangle *s h g:* whence it follows that in uniformly accelerated motions resulting from gravity, the space described during a given time is the half of that which the moveable is capable of describing in the same time, with the acquired velocity uniformly continued.

49. The discovery of the law according to which the force of gravitation acts upon bodies placed near the

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(*f*) It may here be remarked that if the earth turn on its axis the centrifugal force must diminish from the equator to the poles; and as it is always perpendicular to the axis of rotation, its direction at first opposed to gravity becomes more and more oblique to it: its effect in counterbalancing the force of gravitation must therefore be less; hence in going from the equator towards the poles the fall of bodies ought to be accelerated; and thus they are found to be in fact. The space described by a falling body in the first second from quiescence is 16·0815 English feet, at Paris in N. latitude 48° 50′; while at London, in N. lat. 51° 32′ it is 16·0833. And the ratio of these spaces at the equator and at the poles is 1 to 1·0569, according to the most cautious comparison of the results of theory and experience.—Tr.

earth, and which we have mentioned as due to Galileo, is only as it were the first step in an immense course, which it was reserved for Newton to travel over. The principle of gravitation has in his hands germinated with a fecundity which has no other bounds than those of the universe itself. That great philosopher conjectured that this force, the intensity of which does not appear to be sensibly smaller on the summit of the highest mountains than at the surface of the globe, extends itself to the moon, and that combined with the projectile motion of this satellite, compels it to describe an elliptical orbit about the earth. Gravity at such a distance might be diminished by an appreciable quantity; and in order to determine the law of that diminution, Newton enquired from the known motion of the moon in its orbit, and from the ratio between the radius of the earth and that of the same orbit, through what distance the moon, abandoned to its gravity solely, would descend towards the earth in a determinate interval: then comparing this distance with that which measures the descent of a body near the surface of the earth in the same time, he found that the law of gravitation, on the supposition that this force extended to the moon, followed the inverse ratio of the square of the distances. Finally he generalised this result, by considering the sun as the focus of a force which propagates itself indefinitely in space, and which draws or attracts, conformably to the law of which we have just spoken, all bodies placed in its sphere of activity, at the same time that those bodies exert similar actions one upon another. This short exposition will serve to furnish a glimpse at the immensity of the labour undertaken by Newton, and by the illustrious geometers who have perfected his theory, to determine the various modifications of a law so simple in itself yet so complicated in its results, to trace out the mutual influence of phenomena, and to untie the knot by which each of the details is attached to the grand whole.

50. This universal force which furnished Newton with a key to his theory of the system of the world, has been frequently represented by the word *attraction;* which however expresses only a fact, and not a cause; but the law to which this fact is subjected, enables the theory to attain its object, since it brings us acquainted with the manner of action of the cause itself.

On Gravity compared with Attraction at small Distances.

51. The attraction which, as we have remarked, acts in the inverse ratio of the squares of the distances, follows at the same time the direct ratio of the masses; and it is this which renders those effects so perceptible with regard to the bodies that move in the celestial regions: it disappears among those of a volume so minute as to have no proportion with the mass of our globe; but we find it again about us, in the reciprocal actions of the electric and magnetic fluids, where it contributes to the production of phenomena, with a repulsive force conforming to the same law. On the other hand, the moleculæ of solid bodies are bound together by attractive forces, whence their mutual adherence results: and to similar forces must be imputed a great number of the phenomena, where the bodies are found in a state of division in which their elementary particles are isolated: such are crystallisation, the refraction and inflexion of light, the elevation of liquids in capillary tubes, and chemical combinations. The name of *affinity* has been given to the attractive force which produces these different phenomena.

52. Is this force any thing else than gravity modified by circumstances, or does it depend on a particular

cause distinct from that which influences the celestial motions? A great number of philosophers, at the head of whom stands Newton himself, have adopted the latter opinion. They have founded it principally on the circumstance that the attraction in question only commences its action in the vicinity of contact, so that it is very great at absolute contact, and becomes insensible at a distance somewhat appreciable. It would hence follow that this attraction would increase and decrease in a higher ratio than the former, and that probably it would conform to the inverse ratio of the cube of the distances.

53. To comprehend better the difference which, in this hypothesis, would exist between the effects of the two attractions, let us first suppose a spherical body all whose particles act by attractions in the inverse ratio of the square of the distances upon a molecule, situated outward at any distance whatever. Newton has proved that, in this case, the total attraction resulting from all the particular attractions is the same with respect to the particle drawn, as if all the attracting particles had been concentrated at the centre of the sphere*: for if it be imagined that they become all at once placed in that point, the attraction of those below that centre in regard to the particle drawn would diminish in proportion as they were more distant from that particle; but at the same time the attraction of the particles which were situated beyond the centre would increase in proportion as they approached the molecule acted upon. And it can be demonstrated geometrically that in this case a compensation is established between the decreasing attractions and those which undergo the augmentation, in such manner that the sum of the forces retains its primitive value. The term *centre of action* is applied to that

* Princip. Mathem. t. I. prop. lxxi. theor. 31.

point in which we must suppose all the moleculæ of a body to be concentrated, so that their total action shall be still the same as when they were distributed through all the extent of that body. This theorem, of which we have now given an idea, is very remarkable in so far as it leads to our considering spheres as simple gravitating points.

But in the present hypothesis it will never happen that the attraction at contact is infinite, relative to that which had place before the contact; for the radius of the sphere measuring the distance to the centre of action, in the first case, will be always in a finite ratio with the existing distance out of contact; and thus the attractions themselves will be comparable*.

54. We will now suppose that the attraction follows the inverse ratio of the cube of the distances: in this case as the distance diminishes between the moleculæ attracted and the surface of the sphere, the centre of action, on its part, instead of remaining fixed as in the preceding hypothesis, approaches that surface continually, and the attraction increases by a progression whose limit, which obtains at the contact, is infinite; whence it follows that it is then infinitely greater than at an appreciable distance from contact: the same thing will obtain, *a fortiori*, if it be supposed that the attraction diminishes in a greater ratio than that of the inverse cube of the distance. These results, which are comformable to observation in that which passes in the phenomena presented by the elementary moleculæ of bodies, seem to indicate a line of separation between the force that solicits those moleculæ, and that which regulates the great masses of our planetary system.

55. There would, notwithstanding, be a method of conciliating the actions of these two forces, if we

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* Princip. Mathem. t. I. prop. lxxxi. theor. 41. exemp. 2.

adopted the happy idea of Laplace, which consists in supposing that the distances between the moleculæ of bodies are incomparably greater than the diameters of such moleculæ; so that the density of each particle greatly surpasses the mean density of the whole, or that which would have place if all the matter of the moleculæ were distributed uniformly throughout the interior of the body. According to this hypothesis the contact would give a great superiority to the particle attracted, situated in that same point, over the attraction at a finite distance from contact, conformably to observation: and the scene of affinities would thus come under the dependance of the planetary attraction.—Many phenomena, and among others the extreme facility with which the rays of light penetrate diaphanous bodies in all imaginable directions, seem to favour this hypothesis. The diversities presented in the results of affinity would then depend on the form of the elementary moleculæ. But we are yet far from having acquired the necessary knowledge to be in a state to apply any calculus to the intimate actions that bodies moved by affinity exert the one upon the other, and to handle this delicate branch of physics with the instrument by which Newton and his successors have elevated the theory of the celestial phenomena to so high a degree of perfection.

On Specific Gravity.

56. Let it be supposed that a series of bodies of different natures have equal volumes. If all these bodies are weighed successively by means of an ordinary balance, it will be necessary, in order to establish the equilibrium, to employ weights more or less considerable, according as the respective bodies are more or less dense. Let it be supposed, moreover, that having chosen one of these bodies for a term of com-

parison, the lightest for example, we represent its weight by unity, and that we express the weights of all the other bodies by numbers relative to that unit: we shall then have the relation between the weights of the different bodies compared with a common measure, or the *specific gravities* of those bodies.

57. When the volumes of bodies to be examined are not equal, it will be sufficient if we are able to estimate them with such exactness as will allow of a relative comparison; for from that it will be easy to reduce the results of the different objects weighed to what they would have been in the case of a unity of volume. But neither of these two hypotheses will be admissible in practice, independent of the assistance of a hydrostatical principle, discovered by Archimedes on occasion of a problem which, it is said, Hiero, king of Syracuse, proposed to him. That prince, having commanded a goldsmith to make him a crown of pure gold, understood that he had alloyed the metal with a certain quantity of silver, and desired that Archimedes would verify the fact without injuring the crown; and on the supposition such alloy existed, determine its quantity. To give a clear notion of the principle which conducted this celebrated philosopher to the solution of the problem, conceive a body which weighs precisely as much as an equal quantity of water. If this body be held suspended by a thread which we shall here consider as void of gravity, and thus immersed in water, it will not be necessary to employ any force to sustain it, since it is supported entirely by the liquid, which exerts upon it the same effort as it exerted when it kept in equilibrio the volume of water of which this body has taken the place. Conceive now that the body while it retains its volume becomes more heavy; the water will continue to keep in equilibrio so much of the weight of the body as is equal to the primitive weight, or to that of the volume of water displaced; so

that if the body thus immersed were to be weighed, only the excess of its present weight above the primitive weight would act upon the balance. Hence it follows (and it is this in which the principle we have been adverting to consists), that if we weigh first in air and afterwards in water a body relatively heavier than that fluid, it will lose a part of its weight equal to that of the volume of water displaced. By this mean, then, is determined the relation between the weights of bodies and that of water; and thus this liquid serves as a common measure to compare respectively the specific gravities of different bodies.

The balance intended for researches of this kind is called *the hydrostatic balance.* The body to be operated upon is suspended by a hair from a little hook fixed under one of the basins, whence is procured a facility in plunging such body in water that it may be weighed.

58. In order that the experiments may become comparable, it is necessary that the liquid be always the same in respect of its nature and of its density. To ensure this, distilled water is taken, or (when it cannot readily be procured) rain water which has sensibly the same degree of purity, and this water is employed at a given temperature. Brisson, to whom we are indebted for a table of the specific gravities of bodies more extended than any others which had previously appeared (*g*), has adopted the temperature of 14° of the thermometer divided into 80 parts, which answers to 17·5° of the centigrade thermometer (*h*) being chosen as a mean in our climate.

It is more natural to represent by unity the specific gravity of water, which is the term of comparison to

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(*g*) The most comprehensive table of specific gravities we recollect having seen in any English work is given in vol. i. of Gregory's Mechanics. It was formed from a careful comparison of the most accurate tables in existence whether English or foreign.—Tr.

(*h*) Vide art. 162, 163, &c. of this vol.—Tr.

which we refer the specific gravities of other bodies, than to denote it by 1000, or by 10000, as is usually done. The remainder of the calculation will be the same, except that commonly there will be a decimal fraction in the result.

59. We shall render manifest, by an example, the process which must be pursued in determining the specific gravity of a body. Suppose that a mass of gold weighs 6 decagrammes in the air, and that its weight in the water is no more than 5688 centigrammes: subtracting this second weight from 6000 centigrammes, which are equal to 6 decagrammes the first weight, we shall find 312 centigrammes for the part lost by the gold in water, and at the same time for the weight of an equal volume of water. We have, therefore, this proportion: 312 or the weight of the volume of water equal to that of the gold, is to 6000 the absolute weight of the gold, as 1 which represents generally the specific gravity of water, to a fourth term which will give the specific gravity of the gold. It is evident that the operation is reduced to dividing the absolute weight by the loss in water. The unknown term taken with four decimals will be 19·2307 (*i*).

60. It is now easy to comprehend what course Archimedes must have taken to resolve the problem we before mentioned. He need only to know the absolute weight of the crown, its specific gravity, that of pure gold, such as we have stated it, and that of pure silver, which is nearly 10·5. He would find at first that the

(*i*) Although many writers besides M. Haüy think it most natural to represent the specific gravity of distilled water by unity, yet all the arguments they could adduce in favour of it would have little weight in England, when opposed to the remarkable fact that a cubic foot of such water weighs 62½lbs. averdupois, or 1000 ounces: for hence it follows that by assuming 1000 as the specific gravity of water, we not only can exhibit as accurately as by the other method the relative gravities of bodies, but we, at the same time that we learn those relations, learn also the weight of a cubic foot of any proposed body in averdupois ounces.—Tr.

specific gravity of the crown was less than that of pure gold, which alone would indicate an alloy of silver. Having then combined, by means of computation, the several data we have just cited, he would be able to determine the relative quantities of the two metals contained in the crown, excepting the small difference that would result from the circumstance that the volume of the mixture is never entirely equal to the sum of the volumes of the metals taken separately.

61. Gold which had for a long time been regarded as the heaviest of all natural bodies, yields in that respect to a metal named *platinum*, which was discovered in 1741 (*k*), and of which the specific gravity, as de-

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(*k*) The first in Europe who mentioned Platinum or Platina by its present name, was Don Antonio Ulloa, a Spanish mathematician, who in 1735 accompanied the French academicians that were sent by their sovereign to determine the figure of the earth by measuring a degree of the meridian in Peru. In the relation of his voyage, which was published at Madrid in 1748, he says, that the gold mines in the territory of Choco had been abandoned on account of platina; which he represents as a hard stone not easily broken by a blow on the anvil, which could not be subdued by calcination, and from which the gold could not be extracted without much labour, much expense, and great difficulty. The name *platina*, or little silver, is from the Spanish of *Plata*, silver. Bergman changed the name into *platinum*, that the Latin names of all the metals might have the same termination and gender.

This metal, though not under its present name, which was first mentioned by Don Ulloa, has perhaps been known in Europe, as M. Haüy remarks, ever since 1741. At that period Charles Wood found in Jamaica some platina which was brought from Carthagena. He even made some chemical trials of it. Among others, he attempted to cupel it: and observes, in the account which he gave of it in 1749 (see also Phil. Trans. vol. xlvi. pa. 584), that the Spaniards had a method of casting it into different sorts of toys, which are common enough in the Spanish West Indies. It was probably, too, imported into Spain soon after its discovery in America. It is said that Rudenschoel carried some of it from Spain to Stockholm in 1745; and the first important set of experiments that appeared on the subject were those of Scheffer, one of the members of the Swedish Academy. They were published in 1752; and gave this information, that platina is easily fusible with arsenic, but when alone remains unchanged by the most violent heat of the furnace. Two years after Dr. Lewis published some papers concerning this metal in the Philosophical Transactions of London. This eminent chemist, in the course of his experiments, had examined it both in the dry and wet way; discovered a number of its relative affinities; mixed it in different proportions with different metals;

termined by the celebrated Borda, is 20·980. Our knowledge relative to this kind of observations, so truly valuable to the philosopher, furnishes no less advantages to naturalists, as it presents them with one of the most decisive characteristics for the distinction of minerals. Thus we may avoid confounding the blue variety of rock crystal, called *water sapphire*, with that species of fine stone known by the name of *oriental sapphire*, the specific gravity of the former being only about 2·8, while that of the second is nearly 4; and here one is the more interested in escaping the mistake, as the difference between the prices far exceeds that of the specific gravities.

62. The construction of the areometer of Fahrenheit, which serves to ascertain the specific gravity of liquids, is founded on a principle which is merely a corollary from the preceding; namely, that in a body specifically lighter than water, and which of consequence floats in part, the weight of the volume of water displaced by the immersed part is equal to the weight of the whole body. When the areometer is immersed successively in fluids of different densities, its weight is made to vary by the additional weights wherewith it is charged, in such manner that the volume of the part immersed is constant; thus we obtain a common measure serving to determine the specific

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and had fused it with arsenic, though he did not afterwards attempt to separate them.

Dr. Wollaston has lately shewn (Phil. Trans. for 1804 and 1805) that there are two or three distinct metallic substances contained in the ores of platina.

And M. Fourcroy, in his History of the late Discoveries relative to Platina, says, "that after the long and painful researches of which this singular metal has been the object for upwards of forty years, chemistry has succeeded in developing eleven metallic substances in its ore; namely, platina, gold, silver, iron, chromium, and titanium, discovered by himself and Vauquelin in the more or less coloured sands which are always mixed with it, the two new metals of Wollaston, Palladium, and Rhodium, and the other two of Tennant, that is to say, iridium and osmium."—Tr.

gravities of various fluids, referred to that of distilled water. We shall presently give a detailed description of an instrument of the same kind with this areometer, from which a precise idea may be formed.

63. The use of common areometers depends upon another application of the same principle, founded on this, that a body which floats in part sinks deeper in fluids that are less dense than in those that have more density. A common areometer consists of a tube of glass terminated in a ball at its lower part, and divided into equal parts through its whole length. In order that this instrument may adjust itself in a vertical position when it is plunged, another ball containing mercury is soldered below the ball we have been speaking of. But this areometer can only indicate that one liquor is more or less dense than another; it does not give, like that of Fahrenheit, the relation between the two densities.

64. Nicholson has invented an instrument to be employed in determining the specific gravities of solids, which has much similarity to this last areometer, and deserves to be known. It consists of a tube M N (fig. 2.) of tin, surmounted by a shank or stem B made of brass wire, which carries at its extremity a little cup or cistern. This stem is marked towards its middle by a stroke *b* made with a file. The lower part holds suspended from it an inverted hollow cone E G, and ballasted within by means of lead. The weight of the instrument should be such that when it is immersed in water, and afterwards left to itself, a part of the tube should rise above the surface. The cistern which terminates the handle, and which is in form of a spheric segment, is fastened by means of a small tin tube in which the stem B enters with friction. Commonly there is a second cistern larger than the former and placed above it, in the concavity of which it engages by its convexity. Hence this second cistern may be

raised up at pleasure, either for more easily withdrawing the weights it is charged with, as we shall immediately see, or to make some change in their assortment.

The use of this instrument is easy to understand. We must commence by placing in the upper dish or cistern the requisite weight to bring the mark *b* on the stem level with the surface of the water: this is what the French call *affleurer l'aréomètre* (levelling or adjusting the areometer); and the quantity of weights used for this purpose is called the *first charge* of the areometer *. Having taken out this charge, we must put in the same dish the body proposed for the experiment, and which we suppose to be always denser than the water; we then place by its side in the dish the weights necessary to produce the adjustment. This second charge must be taken from the former, and the difference will give the weight of the body in air. Next we take out the areometer to place the body in the inferior basin E; and having again immersed the instrument, we must add new weights in the cup A, till the adjustment is again obtained. These new weights form, with those which were before in the cup, the third charge of the balance. This charge being made less by the second, the difference will give the loss of the body's weight in water, or the weight of the volume of water displaced; after which we must divide by this weight that of the body in air.

65. If we would weigh a substance relatively lighter than water, it will be necessary, when it is placed in the inferior basin, to fasten it so that it cannot rise. In this case the body that serves to fix it is considered as part of the areometer. The rest of the operation is the same as in the preceding case; only, the weight of

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* It is almost unnecessary to observe that the use of the instrument is limited to bodies whose weight in the air does not exceed this first charge.

the body subjected to the experiment, divided by the weight of the volume of water displaced, will give a quotient smaller than unity.

Thus, supposing that the weight of the body being 4 grammes, we had found 5 grammes for the difference between the second charge and the third; it would follow that the body weighs a gramme less than it ought to make its weight represent that of the volume of water displaced, This latter weight being, therefore, 5 grammes, we have $\frac{4}{5}$ or 0·8 for the specific gravity of the body.

66. There are some substances which when immersed in water imbibe that liquid: such, for example, is ordinary freestone. This property is perceived when having placed the body in the lower basin E, it is seen to descend after having remounted, although the dish A continues charged with the same weight. In this case we must suffer the body to imbibe all the water which it can admit into its pores, judging that it has arrived at this point of saturation when the areometer remains in a fixed position; then must the adjustment be made to the middle point of the stem, and we must enquire, as before, what loss the body has sustained of its weight in water. After this we must find the weight of the quantity of water which it had imbibed, by weighing it in the air as speedily as possible, and subtracting the first weight from the second; then we must add the difference to the loss previously found, and the result will give the true loss, or that which would obtain if the body did not possess the imbibing quality; after this the operation must be continued as directed above.

We will suppose that the body weighs 10 grammes before it imbibes the water, and that the quantity of water it has received is 2 decigrammes; suppose moreover, that the loss of weight in water comprising the effect of absorption is 4·3 grammes; as bodies of equal volume lose less of their weight in water in proportion as they are more dense, it results that the body submitted to the experiment has lost 2 decigrammes less than in the case where the absorption does not obtain, since this latter is equivalent to an augmentation of density: it will, therefore, be necessary to add 2 decigrammes to the loss before found, which was 4·3 grammes, the sum or 4·5 grammes is the correct loss. The specific gravity of the body, considered as exempt from absorption, will therefore be $\frac{100}{45}$ or 2·2222, stopping at the fourth decimal place.

67. The double property possessed by this instrument of fulfilling at the same time the functions of a true areometer, and that of a hydrostatic balance, would become useful in the case where it would be disposed in a liquid whose density differs sensibly from that of distilled water, and whose temperature was several degrees above or below that which had been chosen as a term of comparison. It would be easy to reduce the result of the experiment made by means of this liquid, to that which would be given by distilled water at the temperature of 14° of Reaumur (63°½ of Fahrenheit). This operation merely requires one additional piece of information, namely, that of the absolute weight of the instrument.

We shall suppose that this weight is 152 grammes, and that the additional weight commonly required for the first charge when distilled water at 14° of Reaumur is employed, is 20 grammes; thus we have 172 grammes for the sum of these two weights. Suppose now that the weight which constitutes the first charge with the liquid substituted for distilled water is 20·5 grammes, the sum will become 172·5 grammes: but the immersed part of the instrument being the same in both instances, it follows that the weights of equal quantities of the two liquids, or, which amounts to the same, their specific gravities, are in the ratio of 1720 to 1725.

This granted, it is at once evident that the liquid substituted for distilled water gives immediately the absolute weight of the body subjected to the experiment. Let this weight be 11 grammes; we must enquire what quantity the body weighed in the fluid employed has lost of its weight, and which we will suppose to be 4·7 grammes: now bodies weighed in a liquid lose the more of their weight as the liquor is more dense, which amounts to this, that the losses are proportional to the densities of the liquids: we have, therefore, the loss corrected, or that which would have obtained with distilled water at 14° of Reaumur, by multiplying 4·7 grammes into the ratio $\frac{1720}{1725}$ between the specific gravities of the two liquids; this gives 4·69 grammes for the corrected loss: dividing the absolute weight, which is 11, by this number, we shall find 2·3454 for the true specific gravity of the body; had no correction been made we should have obtained 2·3404.

It appears from these details that although the instrument under consideration may be less susceptible of precision than the ordinary hydrostatic balance, it has the advantages of being applicable to a greater variety of purposes, of being less expensive, and more easily transported from one place to another.

68. The movements by the aid of which fishes elevate and depress themselves alternately in water, are due to the faculty possessed by these animals of varying at pleasure the specific gravity of their bodies: they are enabled to accomplish this by means of a bladder, usually double, known by the name of air-bladder, and which is generally placed above the abdominal viscera. A little pneumatic canal, which establishes the communication between the vent and the

bladder, enables the fish to introduce into this species of bag an aeriform fluid, which varies in its nature, according to the different kinds of fishes[*]. The vessel dilated by this air determines relatively to the animal itself, an augmentation of volume causing it to be specifically lighter than the water, so that it raises itself in the fluid without the intervention of the organs of motion; and when it would descend, nothing more is requisite than to expel sufficient air from its bladder, to occasion such a diminution of volume as will render it heavier than the volume of water which it displaces. Some fishes which are deprived of the pneumatic canal appear to act directly upon the air included in their bladder, in order to compress it, or to permit it to dilate itself.

The observations made by Geoffroy, and which that learned naturalist has been pleased to communicate to us, prove that in the two families of fishes named by the French *diodons* and *tetrodons*, it is the stomach which, by being swoln out or contracted, according as the fish introduces air into it, or expels a part of that which previously occupied its capacity, actually performs the functions of the air-bladder; so that the destination of that vessel, which nevertheless always exists, is by the help of a peculiar mechanism to lie between the cavity of the mouth and that of the stomach, to be opposed to the expulsion of air when the fish would elevate itself. Having arrived at the surface of the water it continues to be dilated, and soon produces so great a disproportion between the weight of the back and that of the belly, that the former prevails, and the position of the animal is inverted. In this position it floats at will on the water, becoming

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[*] The reader may find in the discourse on the nature of fishes by *Lacepede* the interesting details into which that celebrated naturalist has gone, especially as they relate to the air-bladder *(vessie natatoire)* of those animals. *Hist. Nat. des Poissons*, edit. in 12mo. t. 1. pa. 147, et seq.

more and more inflated, in such manner that its body, which is naturally of an oblong shape, passes to that of a globe whose surface, set round as with prickly bristles, presents on all parts a defensive armour truly formidable to other fishes, which, after having pushed the globe before them, are forced to abandon the attack.

On the new Unit of Weight.

69. We cannot quit this subject without having explained an operation of specific gravity equally remarkable for the importance of its object, and for the perfection of the methods employed in executing it; namely, that which has led to the determination of the unit of weight in the new system of weights and measures. The common type to which all the branches of this system are referred, is the unit of linear measures, or the ten-millionth part of the distance between the equator and the north pole; to this is given the name of *metre*. On comparing the magnitude of the terrestrial arc extending from Barcelona to Dunkirk, as it was given by the operations of Delambre and Mechain, with that of the arc measured in Peru, about the year 1740, it has been concluded that the required distance, or the quarter of the meridian situated towards the north pole, is 5130740 French toises; whence it follows that the metre answers to a length of 0·513074 toises, or 3 French feet, 11 lines, $\frac{3}{10}$ very nearly, corresponding to 39·37023 English inches.

70. The unit of weight, which is called *gramme*, is the absolute weight of the cube of the hundredth part of the metre of distilled water, taken at its *maximum* of density. It will be seen in the sequel that this maximum does not answer to the term of congelation, but to some degrees above it. These precautions were in

some measure necessary to attach the result to a fixed point to which one might always refer, on a repetition of the experiment. The liquid becomes freed by its distillation from all the heterogeneous particles which would affect its purity; and by taking the maximum of density, we have a limit in the midst of all those variations of volume which result from a change of temperature. Finally, the determination of the absolute weight which would presuppose the experiment made in a vacuum, would still free the result from a heterogeneous and variable quantity, namely, the loss of the weight of water in air, which is neglected in ordinary experiments.

71. Lefebure Gineau was charged with every thing that related to this observation, or rather to this union of operations, all extremely delicate. The precision which he proposed to attain excluded at once a method which, at first glance, appeared very simple, and which consisted in taking a cubic vessel whose side had a given ratio with the hundredth part of the metre, weighing it first alone, and then weighing it again after it was filled with distilled water. The difference between the weights would give the weight of the volume of water employed: but it may be conceived, without entering into details, that the result would be affected with various errors, which it would be impossible either to avoid or to appreciate. Another method has therefore been adopted, susceptible of a much greater exactness: it consisted in weighing specifically in the water a hollow cylinder of copper, whose volume had before been compared with that of the cube whose side is a hundredth part of a metre. The operation made known the weight of the volume of distilled water equal to that of the cylinder, and thence was inferred the weight of the cube of the same water which represented the required unit. We trust it will be gratifying to the reader if we here give a detailed

account of the process followed in order to obtain that result.

72. The machine destined to measure the cylinder had been constructed, with as much care as judgment and ingenuity, by Fortin, one of the most distinguished artists in Paris. Without tarrying to give its description, it will suffice to say that it would render appreciable a difference equal to a two-thousandth or even a four-thousandth of a line: this evaluation was made by means of a lever, one of whose arms is ten times shorter than the other; the whole is so disposed that while the real differences which it is the question to determine occasion in the smaller arm movements equal to those differences, the motions of the larger arm which are decuple, and which hence become perceptible, by means of a nonius applied to the extremity of that arm, shew the two-thousandth of a line measured by the play of the shorter arm.

Notwithstanding all the attention of the same artist in the fabrication of the cylinder, the form of that solid was necessarily found to be affected by a multitude of little inequalities, which might have sensibly influenced the result, had they been neglected; for here an error committed on either of the two dimensions of the cylinder, that is, the height and the diameter of the base is, if we may so speak, a cubic error, and not merely a linear error, as in the determination of a simple distance. The surface of the body must therefore be followed or traced in all its parts from one point to another, and a sufficient number of heights and of diameters must be measured at different places in the bases and of the curve surface, to reduce the capacity of the cylinder, which was the object of the operation, to that of a perfectly regular cylinder of equal volume.

This operation terminated, the cylinder was weighed in the air, employing a process as simple as ingenious, which made the inconvenience disappear that is occasioned by the almost inevitable inequality between the arms of even the best executed balances. The body to be weighed was placed in one of the basins or scales, the other basin being charged with any weights whatever, till the beam of the balance became horizontal. Afterwards the body was taken from the first basin, and known weights substituted for it until the beam had again assumed the horizontal position. It is evident that the weight of this body is exactly represented by the sum of the weights which have been substituted for it, though it may happen that this sum differs from that of the weights on the other side, as a necessary consequence of the faulty construction of the balance.

Besides, the weight of the cylinder in the air ascertained by means of this procedure has the advantage of furnishing precisely the same result as if it had been determined in a vacuum. For first, the weights substituted for the cylinder being of the same matter as that body, their volume would be equal to that of the solid part of the cylinder; and under this relation the loss in the air will be equal on both sides. But farther, there was made in one of the bases of the cylinder a little orifice, which established a communication between the interior air and that of the atmosphere. It hence results, that at the moment of the experiment the interior air was of the same density as that which had been displaced by the cylinder; the surrounding air would therefore be in equilibrio with it, and thus the loss of weight was nothing in that respect.

The cylinder was then weighed in the water, and as the weight which kept it in equilibrio was then solely sustained by the air, it was requisite to estimate the small loss it experienced in that fluid, as no longer common to the cylinder immersed in the water. Regard was also had to the little augmentation of weight which was occasioned with respect to the cylinder, by the air comprised within it. Finally, the result was reduced to what would have obtained in water taken at its maximum of density, and it was found that the new unit of weight, or the gramme, answered to 18·82715 grains of the old French weight, or 15·444 grains of English troy-weight.

73. We shall terminate that which relates to this object by a succinct exposition of the system of new French measures: we have before said (69) that the unit of linear measures, or the *metre*, was a length of 39.37023 English inches. Its subdivisions in parts successively 10 times smaller, bear the names of *decimetre, centimetre, millimetre,* and its successive decimal multiples, those of *decametre, hectometre,* and *kilometre* or *chiliometre.* The same mode of division is adopted for all the other species of measure, and the degrees of the scale relative to each of them are indicated by the same initial expressions annexed to the name of the unit to which they are respectively referred. It is requisite to except the unit in coins, as will be seen immediately.

74. With a view to ensure a facility in reducing, at once, by approximation, a new linear measure to an old one, or reciprocally, it may be observed that the millimetre is very nearly equal to $\frac{4}{9}$ of a line of a French foot, or, which amounts to the same, the line is about $\frac{9}{4}$ of a millimetre. Hence it results that the foot is nearly equivalent to 27 millimetres.

75. The unit of superficial measures for land is a square, whose side is 10 metres; it is called *are*, and is equal to about 948 French square feet, or $39\frac{1}{2}$ English perches.

76. The *stere* is a measure equal to a cubic metre, and destined particularly for the measure of wood for fuel; it answers nearly to 29 French cubic feet, or rather more than $35\frac{3}{10}$ English cubic feet.

77. The unit of the measures of capacity is the cube of the decimetre. It is called *litre*, and is nearly equal to 50$\frac{4}{10}$ French cubic inches, or to 61 English cubic inches. It exceeds the Paris pint by about its fourteenth part.

78. The *gramme*, or the unit of weights, answers nearly, as we have before said, to 19 Paris grains, or to 15.444 English grains. The *kilogramme*, or the weight of a thousand grammes, is equal to about 32$\frac{1}{8}$ troy ounces,

79. The pound in money bears the name of silver *franc*. Its tenth part is called *decime*, and its hundredth part *centime*.

It appertains so much the more to France to see springing from her bosom this new system of measures, which are all referred to a determinate part of the circumference of the globe, as their common origin, since no other country presents so fortunate a position with respect to the arc of the meridian which should be measured; that which crosses France possessing the double advantage of being cut by the mean or medium parallel, and of reposing by its two extremities on the borders of two seas. But this system whose basis is founded in nature, and is in like manner invariable, is equally fitted for the adoption of every nation. Several foreign powers, on the invitation of the French government, sent philosophers of distinguished merit, who, jointly with the commissaries of the National Institute, discussed the observations and experiments whence have been deduced the fundamental units of length and of weight; thus having concurred by their zeal and their knowledge to accomplish this great undertaking. Never did the sciences present a spectacle more worthy of them than that of this society so interesting, which, by furnishing a new proof that the enlightened men of all countries compose only one family, gave in some sort its sanction to this system, the adoption of which might become the pledge of a closer union between the nations themselves *(l)*.

(*l*) Among the various projects for a universal measure which have been laid before the world at different times, there seem few that deserve any consideration except those which are founded upon experiments with pendulous bodies in some assumed position upon the earth's surface, or those which are deduced from the mensuration of some of the lines or circles belonging to that surface. As a universal measure which should be unalterable by time or place, to which the measures and weights of different ages and countries might be referred as an invariable standard, for their comparison and estimation, would undoubtedly be of great utility, especially to the philosophical enquirer, it may be expected that some remarks should here be added, relative to the principal measures which have been derived from these distinct sources.

Huygens, in his Horologium Oscillatorium, was, as far as we can ascertain, the first who proposed the distance from the point of suspension to the centre of oscillation, of a pendulum vibrating seconds, as the length of a universal standard yard, the third part of which was to be denominated *a horary foot*, to which all other measures were to be referred. This standard is liable to two objections: for, 1st. It is not invariable, the length of a second's pendulum, like the space descended in the first second from quiescence (see note at art. 47) being different at different distances from the equator. And 2dly. The difficulty of exactly measuring the distance from the point of suspension to the centre of oscillation is such, that it is probable no two measurers would come to the same result. Several expedients were proposed after this of M. Huygens, but none that deserved any attention, until the year 1779, when a Mr. Hatton, in consequence of a premium offered by the Society of Arts and Manufactures, "for obtaining invariable standards for weights and measures, communicable at all times and to all nations," proposed a plan which consisted in the application of a moveable point of suspension to one and the same pendulum, in order to produce the full and absolute effect of two pendulums, the difference of whose lengths was the intended measure. Here also the ratio of their lengths was easily determined, from observing the number of vibrations performed in a given time at each point of suspension. Whence, there being two equations and two unknown quantities, the actual lengths of the pendulums themselves might be easily deduced by simple algebraic rules. The late ingenious Mr. Whitehurst much improved upon Mr. Hatton's original notion, in his essay published in 1787, under the title of "An attempt towards obtaining invariable measures of length, capacity, and weight, from the mensuration of time, &c." Mr. Whitehurst's proposal is to obtain a measure of the greatest length that conveniency will permit, from two pendulums whose vibrations are in the ratio of 2 to 1, and whose lengths coincide with the English standard in whole numbers. His numbers were chosen with considerable judgment and skill. On a supposition that the length of the second's pendulum, in the latitude of London, is 39·2 inches, the length of one vibrating 42 times in a minute must be 80 inches; and that of another vibrating 84 times in a minute must be 20 inches; their difference 60 inches, or five feet, is his standard measure. The difference in the lengths of the two pen-

5. *On Crystallisation.*

80. After having run over the chief phenomena produced by gravity, we shall find that they naturally lead

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dulums, however, resulting from his experiments, was 59·892 inches, instead of 60, the discrepancy being occasioned by an error in the original assumption of 39·2 inches instead of 39·128 or 39⅛ inches, as it is very nearly. Still, Mr. Whitehurst has accomplished a principal part of his grand design, by showing how an invariable standard may always be found for the same latitude. But this is by no means all that is wanted.

The French philosophers have gone much farther, and have very judiciously deduced the measures of capacity, and those of weight, from the standard linear measure; confining themselves all along to the decimal division. But their system is liable to this heavy objection, that it depends upon an accurate measure of a quarter meridian of the earth, at the same time that no such accurate measure has as yet been obtained; and at the same time probably that the meridians differ so widely among themselves, as to leave no reasonable expectation that a correct medium length of a meridian will ever be obtained.

Some other method, then, must be resorted to, if we wish to obtain a universal measure, which at the same time that it shall be invariable, shall be easily recovered on the supposition the actual standard is lost. Perhaps the least objectionable way would be to take for the length of the *metre* the length of a simple pendulum vibrating seconds at the equator, at a certain height above the surface of the sea, when the thermometer is at a fixed medium temperature; the length of the metre would then be about 39·027 English inches instead of 39·37023, the metre of the new French system. The magnitude of the *are*, the *stere*, the *gramme*, &c. (or any other terms we thought proper to introduce for similar purposes), might have the same relations to the metre as in the French system. Thus should we possess a standard taken from the gravitating force of the globe we inhabit, and which might be safely considered as invariable so long as the constitution of the earth and its time of rotation remains the same. The material standard itself might be chosen of some shape that should possess the double advantage of being little affected by changes of temperature, and being a pendulum whose distance between the point of suspension and centre of oscillation, should be exactly equal to a fixed dimension of the pendulum that might readily be measured with exactness. Such a body we have in a right-angled cone, or one the diameter of whose base is equal to its altitude; for when this cone is suspended by its vertex as a centre of motion, the centre of oscillation is in the centre of its base; and when it is suspended by its base, the centre of oscillation coincides with the vertex of the solid: the length of the isochronous simple pendulum being in both cases equal to the altitude of the cone, or to the diameter of its base. It will be easy for any person who takes an interest in these speculations to pursue the present hint: other readers may perhaps think this note much too long. Tr.

to the exposition of one of the most remarkable results of that other attractive force which we have compared with it, and which only acts in the vicinity of contact. This result consists in the regular arrangement of the moleculæ of certain bodies under geometrical forms. It is to chemistry that the developement of the circumstances appertains which determine the phenomenon, where the moleculæ, at first separated the one from the other by the interposition of a liquid, afterwards approach one another and become united in virtue of their mutual attractions, in proportion as the moleculæ of the fluid go off by evaporation, or by any cause whatever. To this operation has been given the name of *crystallisation*; and that of *crystals* to the regular bodies which are produced by it.

The formation of salts, which takes place daily under our eyes, by the intervention of dissolvents employed by the chemist, is nothing else than an imitation of what is passing in the immense laboratory of nature, and of the manner of operation in the production of all those crystals of different kinds which hang from the interior surface of certain caverns, or are found residing in certain earths.

81. Here a very marked difference between minerals and organic beings presents itself. The vegetable, for example, draws its origin from a germ which the nourishment developes, still retaining its form; and the impression of that form is afterwards transmitted by the way of reproduction, to the individuals the succession of which propagates the species. All have their flowers composed of parts equal in number, and similar both in figure and arrangement; the same relations exist in the respective positions of the leaves, and in their contours whether rounded or angular, whether regular and smooth or dentated. The diversities exhibit themselves only in slight and fugitive shades, so

that it may be said he who has seen an individual has seen the entire species.

But a mineral is only an assemblage of similar moleculæ, joined together by affinity; its augmentation is accomplished by the juxta-position of new moleculæ that apply themselves to its surface, and its configuration, which depends solely on the arrangement of the particles, may change by the effect of various circumstances. Hence that multitude of different forms, and at the same time regular and well defined, which often distinguish the crystals of the same substance. Thus the combination of lime with carbonic acid, or carbonate of lime, presents sometimes the form of a rhomboid, that is (in the sense M. Haüy uses the word) a parallelopiped terminated by six equal and similar rhombi; sometimes that of a regular hexaëdral prism; here it is a dodecaëdron terminated by 12 scalene triangles; there it is again a dodecaëdron, but one whose faces are pentagons, &c.

82. All these different forms which the same mineral is susceptible of taking, and which are sometimes totally removed from one another in appearance, are notwithstanding united by a common bond; and although we have not as yet been permitted to unveil the laws to which the Supreme Being has subjected the forces producing them, we may at least know those which are followed in the arrangement of such moleculæ as concur in their determination. We shall proceed to a brief exposition of the theory of those laws, the consideration of which is within the jurisdiction of Natural Philosophy.

On the Primitive Forms of Crystals.

83. It was remarked long ago that a great number of minerals, especially among those which have regular forms, are composed of laminæ, or thin slices, capable of being separated one from the others, in such manner that the fragments detached from these bodies by percussion have their faces plane, smooth, and more or less bright and sparkling.

84. We have given the name of *mechanical division* (16) to the operation by which we are thus enabled to accomplish as it were the anatomy of a crystal, seizing, by the help of a sharp-edged instrument, such as a thin plate of steel, the natural joints of its constituent laminæ; and this operation executed upon all the minerals that favour the enquiry leads to a general result, which serves as a key to the theory of the laws relative to their structure. It consists in this, that if we divide the different original crystals of the same substance by corresponding sections over all the parts similarly situated, we shall come to the extraction of a regular solid, which is constant for all those crystals, even for those whose forms are most strongly contrasted. Two or three examples will suffice to make this easily comprehended.

85. Let *abef* (Pl. I. fig. 3.) be the regular six-sided prism which is one of the varieties of carbonate of lime; it will be found that among the six edges *in*, *nc*, *cb*, &c. of the upper base, there are three which yield to the mechanical division. Let *in* be one of these latter edges; the mechanical division is made according to a plane *psut* inclined in an angle of 45°, both to the base *abcnih*, and to the plane *inef*. The two ridges *bc*, and *ah*, will admit of divisions analogous to the preceding, without its being possible to operate in a similar manner upon the three intermediate edges *cn*, *ab*, *ih*.

It will be the complete reverse of this with respect to the inferior base *gfedrk;* for the edges of this base which will admit of the divisions, will be opposed to the non-divisible edges of the other base; that is to say, they will be the edges *de, gf, kr.* The plane *lqyz* represents the section made about this latter ridge. We shall therefore have 6 new planes laid open to us by these sections; and if we continue the division always parallel to those sections, until all the faces of the hexaëdral prism have disappeared, we shall arrive at a rhomboid, which is as the nucleus, and which the figure represents in its due position with regard to the prism. The great angle EAI of any one of the faces of this rhomboid, as found by computation, is 101° 32′ 13″.

Every other crystal of the same species will, if divided mechanically, furnish an analogous result. It is merely requisite to find the direction of those sections that lead to the central rhomboid. Thus to obtain, at once, the nucleus of the dodecaëdron formed of scalene triangles (fig. 4), the first plane must be made to pass through the two lines EO, OI,—a second through the lines IK, KG,—a third through the lines GH, HE, and nearly the superior moiety of the nucleus will then be discovered: three other sections made, the one by the lines OI, IK, another upon the lines KG, GH, and the last upon the lines HE, EO, will complete the disengagement of the nucleus. See fig. 5, which represents the nucleus inscribed in the dodecaëdron.

26. Among the varieties of the same substance may be observed several rhomboids very different from the nucleus, as to the measure of their angles. But each of these rhomboids includes another which is still similar to the nucleus. For example, the rhomboid shewn at fig. 6., in which the angle at the summit is acute, and measured by 75° 31′ 20″, is subdivided by planes which intercept the terminal edges; namely, on one

part ns, us, ts, and on the other part ns', us', ts', making equal angles with the faces which they cut. The result is the obtuse rhomboid AA′, having the same angles as that which was drawn from the regular hexaëdral prism, and being so situated in respect of the circumscribing rhomboid, that its faces are parallel to the edges of the latter, as they ought to be from what has been said. That modification of a form which seems as a disguise to itself, has perhaps something still more surprising than the diversities which render other forms like foreigners with respect to their nucleus.

87. If a crystal of another species be taken, the nucleus will be found changed; if it be still a rhomboid, its angles will be different. In such a species it will be a cube, in such another it will be a right prism, with its bases rhombi, &c. We shall call *primitive forms* the forms of those solids which are each inscribed in all the crystals that belong to the same species; and *secondary forms* those which differ from the primitive form. This latter is also sometimes immediately produced by crystallisation.

88. The known primitive forms are six in number, namely, the tetraëdron, which in this case is always regular; the parallelopiped, which is sometimes rhomboidal, sometimes cubic, &c.; the octaëdron, whose surface is composed of triangles which are, according to the species, equilateral, isosceles, or scalene; the regular hexaëdral prism; the dodecaëdron bounded by equal and similar rhombi; and the dodecaëdron composed of two right hexaëdral pyramids united at their bases. The hexaëdral regular prism, which appears here among the primitive forms becomes, as we have seen (85), a secondary form relatively to carbonate of lime; and this is not the only example of that faculty possessed by the same solid of doubling itself in some sort by the variety of its functions.

Forms of the Integrant Moleculæ.

89. We have hitherto confined ourselves to the consideration of the nucleus; since this result of the mechanical division, being a kind of constant quantity relative to all the crystals of the same species, becomes a commodious datum for the theory, which proceeding from this constant quantity, has only to determine the variable quantities, that is to say, the several modes of arrangement of the moleculæ situated in the parts that serve to envelope the nucleus.

90. But before we can pass to the laws of this arrangement, we must ascertain the kind of moleculæ which are proposed for investigation; and it is by the subdivision of the nucleus by slices parallel to its different faces, and sometimes in other directions still, that we attain this knowledge.

We will suppose, at first, that the nucleus is a parallelopiped, which has no other natural joints than those which are parallel to its faces, and we shall choose for example the rhomboid of the carbonate of lime. The subdivision of this rhomboid by planes, always more nearly approaching towards each other, will give rhomboids similar to it, and which successively diminish the original volume; and if this division were continued mentally beyond the term where the little solids would become insensible to the eye, the rhomboids would be brought to such a degree of tenuity, that we could not divide them any farther without analysing them, that is, without destroying the union of the chemical principles which compose them. These rhomboids situated, in a certain sense, upon the limit of the mechanical division, are what we call the *integrant particles* of carbonate of lime, to distinguish them from the elementary moleculæ of the same substance, which are, on one part, those of the lime, and on the other, those of the carbonic acid.

91. For a second example we will take the dodecaëdron with rhombal planes (fig. 7.), which can be no other way divided than parallel to its faces. I say that in this case the integrant particle will be a tetraëdron. To prove this, we shall remark that any one whatever of the edges of the dodecaëdron is parallel to two opposed faces of that solid. Thus the edge *o l* is parallel to the faces *r s y x*, *p u z h*; the edge *p u* is parallel to the faces *o l r s*, *a h z q*, and so of others: on the other hand, any one whatever of the small diagonals of one of these rhombi is also parallel to two opposed faces; for example, the small diagonal passing through the points *o*, *t*, is parallel to the faces *r s y x*, *p u z h*. Therefore if we would subdivide the dodecaëdron parallel to its different faces, by causing, for more simplicity, the cutting planes to pass through the centre, these planes, taken three and three, will always pass through a small diagonal, such as *o t*, and by two edges contiguous to that diagonal, such as *o s*, *t s*, or else *o u*, *t u*; that is to say, these planes will intercept two isosceles triangles *o s t*, *o u t*, upon the surface of each rhombus *o s t u*: but it will pass at the same time through the centre; therefore it will detach tetraëdrons, whose number will be 24, that is to say, double the number of faces. The 8th figure represents separately the tetraëdron, whose exterior face is the triangle *o s t*, and it may be demonstrated that the four faces of each tetraëdron are equal and similar isosceles triangles: it is indeed a consequence of the equality and similitude which exists between the rhombi of the primitive form itself.

92. The regular hexaëdral prism which we shall select for our third example, in like manner only admits of subdivisions in directions parallel to its different faces: it will suffice to cast a slight look at

fig. 9., where are traced, on the regular hexagon representing the base of the prism, lines indicative of the subdivisions, to conceive that the form of the moleculæ is, in this case, an equilateral triangular prism.

93. Lastly we will consider one of the primitive forms, the subdivision of which is not limited to parallelism with the faces. Such is the right rhomboidal prism represented pl. II. fig. 10., which appertains to a substance named *Staurotide* (the cross-stone or the *granatite* of Vauquelin), which is found in the department of Finisterre, where its crystals commonly cross one another two by two. This prism, besides the division parallel to the faces M M, and the base P, admits of others parallel to a plane which would pass through the small diagonal A A, and through that of the opposite base; whence it follows that the integrant moleculæ are here also triangular prisms, but such as have isosceles triangles for their bases.

We shall not speak of the division of other primitive forms, because the bounds which we are obliged to prescribe ourselves will not admit of our entering into the details necessary to remove a difficulty arising from this, that the same division appears to tend towards moleculæ of two different forms. It will be sufficient for us to observe here that we may, by means of a very admissible hypothesis, refer the result to a single form of particle which is the tetraëdron; and besides this, if the difficulty now suggested were to subsist in its full force, it would not affect the basis of the theory.

94. Now, that we may better recur to the remarkable consequence deduced from the subdivision of primitive forms, in relation to the number and to the forms of the integrant particles, let us imagine that it is proposed to determine generally the three most simple geometrical solids. As there must be at least four

planes to circumscribe a space, it is evident that the required solids will be successively terminated by four, five, and six planes; and by selecting from each kind of solid the most simple, we shall have first the triangular pyramid or the tetraëdron, next the triangular prism, and lastly the parallelopiped. But such are the three elementary figures which give rise to that great diversity of crystals presented by nature to our observation. Here we perceive that which we may call nature's familiar device, *economy and simplicity in the means, riches, and inexhaustible variety in the effects, produced.*

The three forms now under contemplation are diversified in the different minerals, by the measures of their angles, and by the respective particular dimensions determinable by the theory, and it is principally on these differences that the distinction of mineral species is founded.

95. But a consideration on which we know not how to insist too much, is that in all the series of crystals which the theory refers to the same primitive form, by the aid of laws of which we shall soon speak, the form of the particle is invariable, relatively to the measure of its angles and to its respective dimensions; and this constancy, which is demonstrated by facts on which it will be enough merely to cast the eyes, and by computations closely connected with those facts, subsists in the midst of all the diversities that modify the composition of a substance. When in the same series of crystals this is limpid and without colour, while that contains a colouring principle, and a third yields by analysis a certain quantity either of iron, or of any other matter of which the other crystals do not furnish the least trace: still there exists one principle common to all the individuals, which is found in excess in some of them, and all those variations, whatever may be their cause, do not even slightly affect the geome-

trical form of the integrant particle: *that* stands as a fixed point about which all the rest seems to oscillate. If therefore there be here a problem to resolve, it is not that which consists in explaining how the constancy of the moleculæ may agree with the changes which intervene in the composition, but those whose object is to reconcile these changes themselves with the immutability which we cannot avoid granting to the form of the moleculæ.

96. The divisions which we have considered in the nucleus extend equally to all the surrounding matter; whence it follows that the entire crystal is nothing else than an assemblage of integrant particles, similar to those of which the nucleus itself is constituted. We shall suppose that these moleculæ are the same that were suspended in the fluid where the crystallisation is accomplished, though we cannot be physically certain of this, since they escape our sight in consequence of their extreme tenuity; but in the study of nature we cannot proceed more wisely than by adopting this principle, *that things are considered such in themselves as they offer themselves to our observations.* The ultimate perceptible results of the mechanical division of minerals, even if they do not give the figure of the true integrant articles, still deserve so much the more to be deposited in our conceptions, as the assuming them for data enables us to represent faithfully the facts presented to us by nature, and to establish their connection and mutual dependance.

The theory which relates to this object consists in investigating the laws followed by the moleculæ in their arrangement, to produce those species of regular coverings which disguise the same primitive form in so many different fashions.

On the Laws to which the Structure of Crystals is subjected.

97. If we consider attentively the figures of the plates which successively cover again the nucleus of a crystal, and which we shall call *laminæ of superposition*, it will be perceived that proceeding from the nucleus they go on by a progressive diminution, sometimes on all sides at once, sometimes in certain parts only. But the difference between each lamina and that which precedes it can only arise from the retrenchment of a certain quantity of integrant particles that are taken from the first till it is equal to the second; and since the edges of the decreasing laminæ are constantly right lines parallel one to another upon the different laminæ, it results that the differences of which we have spoken are measured by the subtractions of one or many ranges of integrant particles. This, therefore, is the enunciation of the problem presented for solution: a secondary crystal being given, and the figure of its nucleus and of its integrant particles being likewise given; supposing, moreover, that each of the laminæ that will be added to the nucleus does not project so far as the preceding, in certain parts, by a quantity equal to one, two, three, &c. ranges of moleculæ; to determine among the different laws of diminution those from which a similar form to that proposed will result, with respect to the number, the figure, and the disposition of its faces, and to the measure of both its plane and solid angles.

This sort of problems can only be resolved by the aid of a rigid calculus; but to facilitate the comprehension of the manner of operation of the laws that serve to determine the results, we shall proceed to construct, by the method of synthesis, some secondary forms, thus rendering palpable, so to speak, the superposition and the variations of the decreasing laminæ superadded to the nucleus.

98. We shall commence with an example quite elementary, drawn from the dodecaëdron having rhombal planes (fig. 11.), which we have before seen (88) ranks among the primitive forms, but which we shall here consider as a secondary form, whose nucleus is a cube. To extract this nucleus it will suffice to take off successively the six solid angles, as *s*, *r*, *t*, &c., each composed of four planes, by cuts directed in the sense of the minor diagonals. These cuts will lay open six squares A E O I, E O O′ E′, I O O′ I′, &c., which will be the faces of the primitive cube.

This cube, being an assemblage of integrant particles of the same form, it will be necessary that each of the pyramids reposing on its faces be itself composed of cubes equal to one another, and to those which constitute the nucleus. But this condition will be fulfilled, if the first plate situated at the base of any one whatever of the six pyramids, have towards each of its edges one range of cubes less than in the case where it would entirely cover the face of the nucleus on which the pyramid rests; and if each of the other laminæ be in like manner diminished at each border of the preceding one, by a quantity equal to one range: for, it is very evident that, in this case, all the laminæ will be composed of cubes solely. This arrangement is represented by fig. 12., where it may be seen that the last laminæ is reduced to a single cube*.

This figure is constructed on the hypothesis wherein the nucleus has 17 moleculæ on each of its edges; and as the laminæ of superposition diminish by one range towards each of their opposite borders, it follows that

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* In the figure only three of the pyramids are superadded to the nucleus; it is easy to supply the others mentally.

the lengths of those edges are successively as the numbers 15, 13, 11, 9, 7, 5, 3, 1, which makes eight laminæ for each pyramid. The triangular faces o *s* I, o *t* I, &c. of these pyramids are produced by the diminishing edges of the laminæ of superposition which are obviously found on the same plane; so that they are alternately re-entering and salient.

But there are six pyramids, and consequently twenty-four triangles. Now, since the diminution is uniform throughout the extent of the adjacent triangles upon the contiguous pyramids, such as o *s* I, o *t* I, it results that the triangles, taken two by two, form a rhombus.

The surface of the solid will therefore be composed of twelve equal and similar rhombi, that is to say, this solid will have the same form as that which is the object of the problem. The obtuse angle of each rhombus is measured by 109° 28′ 16″*, and the inclination of any two rhombi whatever, respectively adjacent, is 120°.

Now if for this kind of gross masonry, but which possesses the advantage of speaking to the eyes, we substitute the infinitely delicate architecture of nature, it will be necessary to conceive the nucleus as being composed of an incomparably greater number of imperceptible moleculæ; then the number of laminæ of superposition being itself considerably augmented, while the thicknesses of those laminæ will have become imperceptible, the channels which those laminæ form by the re-entering and salient alternative of their borders will likewise escape our senses; and it is this which obtains in the polyedræ that are formed so easily by crystallisation, without being either pressed or disturbed in its progress.

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* This is a consequence of this that the ratio between the greater and less diagonals of each rhombus, is that of $\sqrt{2}$ to 1.

To enunciate the result which we have been describing, we say that the dodecaëdron is produced in virtue of a diminution by a single row or range, parallel to all the edges of the cubic nucleus.

99. If it be imagined that the laminæ of superposition decrease by two, three, or more ranges, and always parallel to the different edges of the primitive cube, then the pyramids being more flattened, their faces can no longer be found two by two in the same plane; so that the surface of the solid will then be composed of 24 distinct triangles.

100. We shall call *decrements in breadth*, those where each lamina having only the thickness of one particle, as in the case we have just cited, suffers an abstraction from the preceding one, by a quantity equal to two, three, or more ranges. The *decrements in height* are those which present the inverted effect, that is to say, where each lamina suffering only an abstraction from that which precedes of a quantity equal to one range, may have a height double, or triple, or quadruple, &c. of the thickness of a particle. The limit of these two species of decrements has place when the difference in breadth and the dimension in height are both equal to the unit, as in the dodecaëdron with rhombal planes originating from the cube (98).

101. The dodecaëdron from sulphurets of iron (ferruginous pyrites), the surface of which is composed of 12 equal and similar pentagons, as may be seen in fig. 13., offers us a combination of the two species of decrements we have been speaking of. Each pentagon, such as *t* o *s* o′*n*, has four equal sides, namely o*t*, o*s*, o′*s*, o′*n*; the fifth *t n*, which we shall consider as the base of the pentagon, is longer than the others. The dodecaëdron, which is here the subject of enquiry, has again a cube for its nucleus, at the extraction of which we should arrive by causing the

cutting planes to pass through the diagonals O I, O E, A E, A I, &c. (fig. 14.), which intercept the angles opposite to the bases; whence it appears that the portions superadded to the nucleus, instead of being pyramids, as in the dodecaëdron with rhombal planes, are a species of wedges that have for exterior faces two trapezoids, such as O I *q p*, A E *p q*, and two isosceles triangles E *p* O, A *q* I.

Each of these additional parts, that, for example, which we have just pointed out, results from two decrements, the one through two ranges in breadth parallel to the two opposite edges O I, A E, of the corresponding face A E O I of the nucleus, the other through two ranges in height, parallel to the two other edges E O, A I, of the same face: moreover, each decrement acts upon the different faces of the cube according to three directions respectively perpendicular. Thus the decrement through two ranges in breadth obtains upon the face A E O I, parallel to O I, and A E, as we have said, acts upon the face O I I′ O′, parallel to O O′ and I I′, and upon the face E O O′ E′, parallel to E O and O′ E; and in the same directions upon the opposite faces. The progress of the decrement in height through directions which intersect it also at right angles, is presented to the mind of itself, after the elucidation just given.

On considering attentively the 15th figure, where we have rendered sensible to the eye the distinction of laminæ of superposition and the moleculæ of which they are the assemblage, it will be seen that the progress of the decrement in breadth, which contributes for example to the formation of the additional part E O I *q p*, and which takes place parallel to the edge O I and to its opposite, being more rapid than that of the decrement in height, which is made parallel to the edge O I and to its opposite, the two faces that spring from the former must be more inclined than those which are produced by the second; in such sort that each pile of decreasing laminæ no longer terminates in a point, but in an edge *p q:* moreover, each trapezoid, such as o *p q* i (fig. 14.), which results from the decrement in breadth, being upon the same plane with the triangle o *t* i, in consequence of this that the decrement in height which determines the latter is only the repetition in a contrary direction of the decrement in breadth, the aggregate of the two figures forms a pentagon *p* o *t* i *q;* whence it follows that the secondary solid is terminated by 12 equal and similar pentagons, by reason of the regular figure of the nucleus, and of the symmetry of the decrements.

If it be supposed that the decrements act according to two other laws, one of which is always the inverse of that which is combined with it, in such manner that there shall be three, or four, &c., ranges, subtracted in breadth and as many in height, the result will still be a dodecaëdron of twelve equal and similar pentagons; and it is very evident that all these dodecaëdrons will differ, either from one another, or from the preceding dodecaëdron, by the measure of their angles. In order that the law on which we have made the latter inference depend may be demonstrated, it is necessary that the inclination[*] of each pentagon, as *t* o *s* o′ *n*, upon the pentagon *t* i *s′* i′ *n*, which has the same base *t n*, when measured upon the natural dodecaëdron, be equal to that which is determined by the calculus, taking for a datum the law now under consideration, and which inclination is 126° 52′ 8″[†]: but, the gonio-

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[*] It may be easily conceived that the inclination to which we have given the preference, determines all the other angles.

[†] To find this inclination nothing more is requisite than to resolve a right-angled triangle *a b c* (pl. III. fig. 16,, in which the side *a b* is to the side *b c*, as the distance between the edge of one lamina and that of the following, given by the decrements in breadth, is to the thickness of each lamina, that is to say, as 2 to 1, The angle *a c b* will be the half of the inclination sought. Haüy.

The

metry (the actual measure of the angle) gives sensibly 127°; whence it must be concluded that the first measure is the limit to which the instrument would of itself reach, were it not for the little imperfections, which do not permit it to offer us more than approximations. What is here remarked obtains equally in all the other applications of the theory: every law of decrement furnishes its respective result, the agreement of which with that of observation is full as satisfactory as can reasonably be desired.

102. The solid, the structure of which we have been explaining, has been taken for a regular dodecaëdron similar to that of the geometers, since persons were led to attribute to crystals the forms that appeared the most simple and the most regular, when a polyedron is considered merely in its aspect, and as the phantom of a physical body; but the theory demonstrates that the existence of a regular dodecaëdron is not possible in virtue of any law of decrement. The reason is that the ratio of the quantity of which each lamina is deprived by the following in the direction of its breadth, to the thickness of the same lamina, must always be represented by rational numbers; which obtains effectively in the dodecaëdron of sulphuret of iron, where this ratio is that of 2 to 1: on the contrary, the ratio between the two corresponding dimensions in the regular dodecaëdron is expressed by irrational numbers, that is to say, it represents an impossible thing*. But the defect of symmetry existing in the exterior of the dodecaëdron of sulphuret of iron conceals a character

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The angle *a c b* is obviously that whose tangent is double the radius, which by inspection in any table of natural tangents is at once seen to be rather more than 63° 26′. Tr.

* This ratio is that of $\sqrt{3+\sqrt{5}}$ to $\sqrt{2}$, as it will be easy for geometricians to assure themselves; and the measure of the angle formed by the two adjacent faces, is 116° 33′ 32″, instead of 126° 52′ 8″.

of simplicity, which consists in this, that the particle being a cube whose figure is remarkable for its perfection, the law of the decrement is, at the same time, that which produces the dodecaëdron by the aid of the least possible number of subtractive ranges; thus it may be truly said that it is the regular dodecaëdron of mineralogy.

103. We shall terminate that which regards decrements on the edges, by an example drawn from the dodecaëdron whose faces are scalene triangles (pl. I. fig. 4), which is, as we have seen (84), one of the varieties of carbonate of lime. Here the nucleus is a rhomboid, the axis of which, that is to say, the line passing through the two solid angles A, A′ (fig. 5.), composed each of three equal obtuse angles, must be situated vertically, that this rhomboid may be presented to the eye under its true aspect; it results, that symmetry does not require as with respect to the cube, that the decrements operating on any one E O of the edges of one of the faces, as A E O I for instance, should be repeated on the opposite edge A I; since the latter, which is contiguous to one of the summits, has in some measure a mode of being different from the other. It is enough that all which takes place with regard to the edge E O obtains equally in respect of the five others, O I, I K, K G, G H, H E, similarly situated. One may judge, solely from an inspection of the figure, that these six edges, which are common to the nucleus and to the secondary crystal, serve as lines of departure to so many decrements, the effect of which is to produce on the two sides of the same edge, such as E O, two triangles E *s* O, E *s*′ O; thus making in all twelve triangles, six towards each summit.

But it is demonstrable by the calculus that, in the present case, the decrements are made through two ranges in breadth, as may be seen fig. 17, pl. III., which is limited to the tracing the species of the superior pyramid added to the nucleus. The salient and re-entering alternatives that are formed by the laminæ of superposition towards their decreasing edges, being nothing as to sense in the crystal produced by nature, the line E *s* will represent one of the edges contiguous to the summit, such as it will be seen on the same crystal; the difference between the geometrical summit *s*, and the physical summit *s*′, vanishing by reason of the extreme minuteness of the particles.

While the laminæ of superposition diminish towards their inferior borders, they augment on the contrary towards their superior borders; and it is a general principle that the portions of the laminæ situated out of the reach of the decrements extend themselves, as if they were to make the nucleus while it retains its form simply augment in volume. But the theory drops the consideration of these subsidiary variations, to contemplate only the immediate effect of the decrement, which alone determines all the rest.

One result which obtains generally for all the dodecaëdrons produced in virtue of the same law, whatever are the primitive angles, consists in this, that the axis of each of these dodecaëdrons is triple the axis of the nucleus, and in this likewise, that the ratio of the solidities is the same as that of the axes: moreover, it is found by means of computation, that in the particular dodecaëdron now the subject of enquiry, the great angle O E *s* (fig. 5., pl. I.) of each of the faces is strictly equal to the obtuse angle E A I of the nucleus (that is to say, 101° 32′ 13″); and that the incidence of the two contiguous faces O I *s*, K I *s*, upon the dodecaëdron, at the place of one of the most salient edges I *s*, is equal to that of the two faces likewise adjacent E A I O, G A I K, towards the same summit of the nucleus, namely, 104° 28′ 40″. It is this that has suggested the name of metastatic, which has been given to this variety, and which indicates the transference, as it were, of the angles of the nucleus to the secondary crystal. The solutions of problems relative to the structure of crystals have served to unveil a multitude of similar properties, and of results of a geometry which would appear worthy of being attentively studied, even when it carries us no farther than its simple speculations: but this study presents a double interest, when those properties, of which it furnishes the developement, have a real foundation in the geometry of nature.

104. Independently of the decrements which have place parallel to the edges of the faces of the nucleus, others are made also in directions parallel to the diagonals; and as they have the angles for terms of departure, we shall call them *decrements on the angles.*

Let o I I′ o′ (fig. 18. pl. III.) be one of the faces of a cubic nucleus, subdivided into a multitude of little squares, which will be the bases of so many moleculæ. The ranges or rows of moleculæ may be considered, not only in the direction of the edges, as the range lying in the direction *a a′*, but also in the order of the diagonals, as the ranges, one of which is denoted by *a*, *b*, *c*, *d*, *e*, *f*, &c., another by *n*, *t*, *l*, *m*, *p*, *o*, *r*, *s*, a third by *q*, *v*, *k*, *u*, *x*, *y*, *z*, &c.; the only difference is, that here the moleculæ of the same range merely touch by an edge, instead of which those that compose the ranges parallel to the edges touch one another by one of their faces. We shall limit ourselves to a single example of decrements on the angles.

105. The 19th figure represents a regular octaëdron, having a cubic nucleus, the solid angles of which (as may be seen in the figure) correspond to the centres of the faces of the octaëdron: in this case the laminæ of superposition diminish by one range over the angle of the faces of the cubic nucleus; it results with regard to the angle I′ (fig. 18.) which we have selected for an example, that the cube which answers to *i* is taken

away by the first lamina, that in the second there will be an abstraction of two cubes, answering to *s*, *s′*; in the third, those which correspond to *z*, *h*, *z′*, and thus throughout; so that the edges situated on the same side, upon the different laminæ, succeed in right lines, such as B B′, D D′, G G′, &c.

Now from the principle (103) that wherever the decrement does not operate, the crystal augments itself on the contrary, as if the nucleus had only to increase its volume, the laminæ of superposition extend themselves towards the parts situated between their decreasing edges, in such a manner as to envelope them mutually until the decreasing edges of the same lamina come to touch one another; there then remains only the effect of the decrements, which continue their progress until they have arrived at their limit.

Each of the eight solid angles of the cube will therefore become the point of departure of three decrements, which will have place upon the three planes that concur in the formation of that angle, whence it follows that there are in all 24 faces produced in virtue of the decrements. But since the decrements obtain by a simple range, it will again happen here that the three faces which arise about the same solid angle are on a level, and thus the 24 faces are reduced to 8; and, in consequence of the regular form of the nucleus, the secondary octaëdron is itself regular. This structure is that of a variety of sulphuret of lead, known commonly under the name of *galena*.

In the same case, and in general in all those which have a relation to the decrements on the angles, the faces of the secondary solid are no longer furrowed by small channels, as when the decrements are made on the edges; they are thick-set with a number of salient protuberances, formed by the exterior solid angles of the moleculæ: but all these angles being on a level, and the moleculæ being besides imperceptible, the faces of the crystal appear to form smooth and continued planes.

The 20th figure represents the assortment of little cubes that concur to produce one of the faces *s m n* (fig. 19) of the octaëdron we have been speaking of. The cube *o* (fig. 20) is situated at the solid angle of the nucleus marked with the same letter (fig. 19). The cubes whose faces are traversed diagonally by the lines *b c*, *c r*, *r b* (fig. 20), appertain to the three first laminæ of superposition which repose on the faces of the cube adjacent to the angle *o*; those which are crossed diagonally by the lines *l d*, *d g*, *g l*, appertain to the three following laminæ. Beyond this term the diminishing edges touch one another in such manner that each lamina takes the figure of a square, of which the side contiguous to the face *s m n* is *k u*, *x y*, or *h z*; and all proceed then by laminæ of this same figure, which go on diminishing on all sides at once, to the summits *s*, *m*, *n*, of the octaëdron, where the laminæ are each reduced to a single cube.

106. The laws of the decrements are susceptible of certain modifications, which offer a kind of medium terms between those we have spoken of; but this is not the place to exhibit them, because our design has merely been to expound the general principles of the theory, and to give an idea of the most usual results to which the application of these methods may be extended.

We have confined ourselves also to the consideration of those forms which depend upon a single law of diminution, and which we call *simple secondary forms*. But crystallisation very frequently presents forms which we term *compound*, and of which the faces are produced by the concurrence of several laws of decrement; when some one of these laws does not attain its limit, its effect remaining as it were interrupted, the secondary presents faces parallel to those of the nucleus, interposed between the little faces which are due to the decrements.

107. What combinations are comprised in the numerous modifications of these laws, which by turns separate over different bodies, and exhibit in the same body the assemblage of many forms, acting sometimes in preference upon certain edges or certain angles; at others, on edges and angles at once, multiplying equally by the diversity of their measures, and by that of their terms of departure; sometimes completely disguising the nucleus; at others,, permitting its image to subsist, and making the constant positions of its faces serve as a basis for new variations! And if it be supposed that the number of subtractive ranges are themselves variable, and that there may obtain decrements by 20, 30, 40, or more ranges, the imagination will be staggered at the immense quantity of regular bodies with which only one substance might people the subterranean world; but the force which produces the subtractions appears to have a very limited action, and hitherto we have not discovered any laws whose measure exceeds six ranges. Nevertheless such is the fecundity which is allied with this simplicity, that when limited to ordinary decrements by one, two, three, and four ranges upon the edges and upon the angles of a rhomboid, it may be demonstrated that this species of nucleus is susceptible of producing eight millions, three hundred eighty-eight thousand, six hundred and forty (8,388,640!) varieties of different forms, while the number of those which have been hitherto observed extend but little beyond sixty, even relative to carbonate of lime, which is deemed the proteus of minerals.

108. We shall not enter here into any details respecting the structure of the secondary forms, whose particle is a tetraëdron or a triangular prism; but we believe we cannot terminate this subject better than by

the exposition of a result which serves to connect this structure with that of the native forms of the parallelopiped. The connexion we now advert to consists in this, that the tetraëdral, or the triangular prismatic moleculæ, are always so assorted in the interior of the primitive form and of the secondary crystals, that, taking them by little groups of two, four, or six, they compose parallelopipeds; so that the ranges taken away by the effect of the decrements, are nothing else than sums of these parallelopipeds.

109. Thus in the regular hexaëdral prism, of which the hexagon A B C D F G (fig. 9. pl. I.) represents the base subdivided into triangles, which are the bases of so many moleculæ, it is evident that any two contiguous triangles, such as A *p i*, A *o i*, compose a rhombus; and, consequently, that the two prisms to which they belong, form, by their re-union, a right prism having rhombal bases, which is one of the species of parallelopipeds.

Let us suppose a series of laminæ piled upon the hexagon A B C D F G, and which undergo upon their different edges, for example, substractions whose measure is such that these same edges become successively in the relative position of the sides of the hexagon *ilmnrh*, *kuxyge*, &c., the effect will be the same as that of a decrement by a range of little parallelopipeds, each composed of two moleculæ. It may be conceived that in the same case the result of the decrement is a right hexaëdral pyramid, whose base stands upon the hexagon A B C D F G.

110. Recurring again to the dodecaëdron with rhombal planes (fig. 7.), which we have seen (91) is an assemblage of tetraëdrons, whose faces are equal and similar isosceles triangles: if we divide the twelve rhombi into four assortments, each constituted of three planes, such as those which are re-united to form any

one of the four solid angles *o*, *y*, *z*, *g*, we may consider each assortment, that for instance which comprises the three planes *o l r s*, *o u t s*, *o l p u*, as appertaining to a rhomboid which should have one of its summits situated exteriorly in *o*, and of which the other summit, engaged in the dodecaëdron, should be confounded with its centre. But it is very obvious, that, on this hypothesis, the twenty-four tetraëdrons, of which the dodecaëdron is the assemblage, effect a junction, six by six, to form the four rhomboids which have their exterior summits at the points *o*, *y*, *z*, *g*. It follows as a necessary consequence, that if we suppose the mechanical division pushed to its limit, all the tetraëdral moleculæ corresponding to that limit, grouped in like manner, six by six, will give rhomboids. But it is by making the laminæ of superposition decrease by one or by several ranges of these rhomboids, that the theory attains to the determination of the secondary forms of substances which, like the granate, have the dodecaëdron with rhombal planes for the primitive form.

111. We have given the name of *subtractive particles* to those parallelopipeds composed of tetraëdrons, or of triangular prisms, the ranges of which measure the quantity of the decrement experienced by the laminæ of superposition. The calculus need only attend to these parallelopipeds to arrive at its object; and the kind of dissection afterwards undergone by these little solids, when we endeavour to attain the true form of the integrant particle, is an affair of pure observation, foreign from the theory. The parallelopiped here represents the unit of the fractions formed of its subdivisions. By means of this conformity between the results given by the various forms of integrant particles, the theory has the advantage of being able to generalise its object, by referring to the same ele-

ment that multitude of forms which, by their diversity, would seem little susceptible of concurring in a common point *(m)*.

(*m*) The Abbé Buée published in the year 1804, in Nicholson's Philosophical Journal and Tilloch's Philosophical Magazine, a very able comparative sketch of the outlines of the Mineralogical systems of Rome de L'Isle, and the Abbe Haüy. As it was M. De L'Isle who first called the attention of naturalists to crystallography, we shall throw into this note a brief account of his method, chiefly in the language of M. Buée.

The most important part of M. de L'Isle's work is his crystallographical tables. In each of these tables he describes one of the principal forms assumed by crystals, and then delineates the different modifications of which that form is susceptible by means of different troncations (*troncatures*), as he calls them.

'For elucidation let us take a cube, the primitive form of the second table. A cube, it is known, has six faces, eight solid angles, and twelve edges. If the cube be truncated in a parallel to one of its faces, a rectangled parallelopipedon will be produced, and the equality of the faces will be destroyed.

'If the eight solid angles of the cube be struck off, eight new faces will replace the eight solid angles, and instead of six sides we shall have fourteen. If the twelve edges be taken off, twelve new faces will succeed the strait lines, and the solid will have eighteen sides. Such are De L'Isle's *simple troncations*. They may be then combined with each other, and made more or less deep; hence an immense variety of new figures. But these new forms again may be truncated in the directions either of their faces, solid angles, or edges; and these new troncations more or less deep, called by De L'Isle *sur-troncatures*, may also be combined with each other. Here the forms must multiply to infinity, and their boundless numbers will soon bury the primitive cube in oblivion.

'It must not be supposed that nature has furnished us with this infinite series of forms; indeed M. De L'Isle in his tables has only mentioned those he had observed, with some few additional supposititious figures, of which several have been since discovered to exist.

'This ingenious naturalist has given us seven crystallographical tables. In the 1st he describes the tetraëdron and its modifications; in the 2d the cube; in the 3d the rectangular octaëdron; in the 4th the rhomboidal parallelopipedon; in the 5th the rhomboidal octaëdron; in the 6th the dodecaëdron, with triangular faces, and to each are subjoined their respective modifications. The object of the 7th table is to point out certain modifications of the octaëdron and parallelopipedon, whether rectangular or rhomboidal. Plates accompany each table, where the figures are drawn, and in the observations and notes on them are to be found the measures of the principal angles.

'These crystallographical tables exhibit only general representations of solids, which M. De L'Isle in the course of his work applies to the different crystals which had already been discovered, and fallen within his observation. His work consists of three parts. In the first he treats of saline crystals; in the second of stoney (*pierreux*) crystals; and in the third of metallic crystals.

6. *On Heat.*

112. In all that we have hitherto said relative to solid bodies, we have considered their moleculæ as united together in an invariable manner, by the force of affinity, and we have only attended to the different modifications of figures which might result from their arrangement. But affinity itself, or, rather, the adherence which it produces between the moleculæ, is susceptible of an infinitude of variations, depending upon a cause which balances more or less of the effect of affinity, and often terminates by destroying it entirely.

Those of the first class are artificial, those of the two latter classes are natural crystals, and are subdivided into genera, species, and varieties.

'When treating of a species or of a variety, he refers his reader to the table where the figure of that species or variety is to be found, and he then enumerates every thing relating to minerals assuming that crystalline form: but I cannot terminate this sketch better than by the following extract from the Abbé Haüy's treatise on mineralogy.

'"In short Romé de L'Isle reduced the study of crystallography to principles more exact and more consistent with observation. He classed together, as much as he was able, crystals of the same nature. From among the different forms belonging to each species, he selected one which appeared to him to be the most proper, on account of its simplicity, for the primitive form, and then supposing it to be truncated in different manners, he deduced the other forms, and established a certain gradation or series of passages from the primitive form to that of polyëdrons, which would scarcely appear to have any connection with it. To the descriptions and figures which he gave of the crystalline forms, he added the mechanical measurement of the principal angles, and he shewed (a most essential point) that these angles were constantly the same in each variety. In a word, his crystallography is the fruit of immense labour by its extent; almost entirely new in its object, and of great value for its utility." Vol I. page 17.'

It will hence be seen that M. De L'Isle embraces a more narrowly limited extent than M. Haüy; the mineralogy of the latter being not only descriptive, but physical, chemical, and geometrical: it may also be added that the method of De L'Isle is deficient in correctness, and may indeed be employed to establish falshood; for by his method forms of the same species may have different primitives; or any form may be assumed as primitive, and any other deduced from it. A circumstance which, however it may be the result of ingenuity, is far from tending to stamp conviction. Tr.

This cause is that which most philosophers have called *heat*, and which the modern chemists denote by the name *caloric*, a denomination which we shall adopt.

113. Is *caloric* any thing else than the effect of an intestine motion, in virtue of which the moleculæ of bodies are solicited to recede from, or approach to, one another, according to circumstances? Or rather, is it a real substance, a subtile and elastic fluid, penetrating all bodies, removing their particles farther asunder, or permitting them to approach each other, according as its quantity augments or diminishes in each of those bodies? Without deciding any thing between these two opinions, we shall adopt the language which is conformable to the second, regarding it solely as an hypothesis more proper to assist the conception of phenomena, and more commodious in expression.

We shall adopt a like method on all similar occasions, and particularly when we shall treat of electricity and magnetism, denoting by the word *fluid* the two principles chiefly operative in the effects, either electric or magnetic; not for the purpose of expressing beings whose existence is not sufficiently demonstrated, but to present, by the imagination, a subject to the action of known forces that contribute to the production of the phenomena. Still, however, we shall not lose sight of the difference between the actual fluids which we can feel, and can confine in vessels; and those agents respecting the existence of which observations have not, as yet, completely satisfied us. We do not, therefore, place them in nature, but solely in the theory, since they possess the advantage, when judiciously selected, of representing results faithfully, of furnishing a satisfactory explication, and even of aiding us to foresee future appearances; so that if they are not the true agents employed by nature in the production of phenomena, they are reputed as occupying their place and existing as their equivalents.

We shall insist the more on this remark, since it appears essential to the progress of the sciences to carry along with us, throughout their study, that exactness and precision of ideas, that correct and rigorous method, which reduces every thing to its true level, which prevents us from saying more of nature than she has actually revealed to us, and from confounding an hypothesis purely explicative, with a distinct and perspicuous view of objects having a real foundation. Natural philosophy may be compared to a picture which, to be happily executed, must cause to appear that expressive shading which separates certainty from simple probability, and in which must be recognised by turns a hand bold and steady in the traits that are strongly delivered, and a hand discreet and well-regulated in those which require to be softened down. But it is time to return to the subject which had begun to occupy our attention.

It is to chemistry that still appertains the developement of the effects depending on the manner in which caloric acts in the composition and decomposition of bodies. We shall consider it especially in its ordinary state, and under a physical point of view.

On the Equilibrium of Caloric.

114. To facilitate the understanding of the details relative to the object which is now to employ us, it will not be useless to present in this place, as by anticipation, an idea of the thermometer. This instrument is composed of a tube, terminated at one end in form of a ball, and partly full of a fluid whose dilatations and contractions shew the variations that are under-

gone in the temperature of bodies communicating with the thermometer. The result is, that the column of the liquid within the tube is lengthened and shortened in proportion as the heat augments and diminishes, or, if you please, in proportion as the temperature is elevated and depressed. The movements of the column are measured by the aid of a graduation, in which two limits are to be distinguished, one of them answering to the point of depression of this column when the temperature is that of melting ice, and the other to the point of elevation of the same column when the temperature is that of boiling water. In the thermometer said to be *Reaumur's*, and in that which is called *centigrade*, the zero of the scale indicates the term of melting ice; but in the former, the interval comprised between this term and that of boiling water is divided into 80 parts, and in the second, into 100 parts. The subdivision is continued in both thermometers, below zero, in parts equal to those which subdivide the interval between the two limits *(n)*.

We must not omit to mention that when the thermometer is employed as an indicator of the temperature of the air, or of any other body, it is supposed that the mass of that instrument is so small that the quantity of caloric which it yields, or which it takes away from the surrounding substances, may be neglected without sensible error. We shall give, in the sequel (159, &c.), a more expanded description of the thermometer, together with the theory of its construction.

115. The presence of caloric, or rather its accumulation beyond the term which it had before attained, is

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(n) In Fahrenheit's thermometer, which is still most commonly used in England, the 32d division is that at which water begins to freeze, or snow begins to thaw, and the 212th division marks the temperature of boiling water: the subdivisions are continued upwards or downwards, with respect to these principal terms, at pleasure. Tr.

manifested to us principally by two effects: the one, which has an intimate relation with ourselves, is the sensation of heat; the other, which is the result of a general observation relatively to all bodies, consists in their dilatation, or their augmentation of volume.

These two effects proceed from the tendency possessed by caloric of remaining in equilibrium with itself; and it is necessary, before all, that we exhibit a just idea of the conditions which determine this equilibrium.

116. Suppose that a homogeneous substance, such as a mass of air, is penetrated by caloric. This fluid will diffuse itself uniformly through all the mass, in such manner that in whatever place of that mass a thermometer be posited, it will indicate the same degree of heat; and it is in this uniform distribution of caloric that its equilibrium consists, relatively to the case which we are here considering.

Let us now conceive that there are placed in the same atmosphere different bodies possessing respectively an equal temperature, but lower than that of such atmosphere; a part of the caloric with which this latter was penetrated will abandon it in order to introduce itself into those different bodies, wherein it will continue to accumulate, until there is a uniformity of temperature in the system composed of those bodies and of the surrounding atmosphere. At that time the caloric will again be in equilibrio with itself; but it does not follow that the different bodies in question have taken away equal quantities of caloric from the atmosphere in which they were immersed. The quantity of caloric absorbed by each body will depend on the greater or less disposition of that body to admit and retain the caloric in its interior, the proportion of its particular affinity for this fluid, the figures of its pores, and other circumstances. It is this greater or smaller disposition of a body to be accessary to the accumulation of caloric, that is named in general *the capacity for heat.*

Here therefore may be comprehended the manner in which the equilibrium is established by means of the repartition which is made between different bodies, of the caloric yielded by some and taken up by the others. In proportion as the caloric accumulates in these, their affinity for that fluid goes on diminishing: for it is known to be a general law of affinity, that its action is weakened in proportion as the body which exerts it approaches to its point of saturation. The contrary happens with regard to the former bodies that are yielding their caloric; their affinity for that fluid goes on augmenting. But it is at the term where the equilibrium obtains between the affinities of the different bodies for caloric, that the whole system, considered under this relation, is itself found to have attained the state of equilibrium.

117. One particular cause influences the duration of the passage to this state of equilibrium: that cause is the faculty of conducting the heat, that is to say, the greater or less facility or promptitude with which the caloric is propagated in the interior of bodies of different natures: for example, metals are very good conductors of heat; while glass, resin, and other similar substances, only possess the faculty of conducting it feebly. The artist who blows a ball at the extremity of a glass tube, holds the tube with impunity at a distance sufficiently small from the part which is in a state of incandescence, while it would be impossible for him to sustain the heat which would be acquired, in like circumstances, by a tube of iron, or of some other metal.

118. We have not made known all which passes in the phenomenon now under consideration. Independently of the portion of caloric, whose communication between different bodies depends upon their affinity for

this fluid, there exists another which is not obedient to such affinity, and which we call *radiant caloric*, since it escapes in virtue of its expansive force alone, under the form of rays susceptible of being reflected by the surfaces of bodies, and especially by those of polished metals. Radiant caloric has that also, in common with light, that it freely traverses the air, in such manner as to be transmitted in a right line from one body to another; and then, according to circumstances, it either retains its radiant property, or becomes again susceptible of uniting, by affinity, with the bodies that are presented to it upon its passage. In the change of temperature undergone by different bodies that tend towards an equilibrium, the quantity of radiant caloric taken up by each body is greater or less than that which it yields to others. But the equilibrium has place when all the affinities of the bodies for caloric are satisfied, as we have before said, and when, at the same time, each body sends forth to others as much radiant caloric as it received; and this equal repartition continues so long as the system remains at the same temperature.

119. Scheele is the first philosopher who has considered radiant caloric*; and the sagacity is astonishing with which he has seized all the characters at an epoch when this subject was entirely new. The better to study the manner of action of this fluid thus modified, he had selected one of the circumstances in which the phenomena that it produces are exhibited in a more perceptible manner, namely, that in which it issues from a stove or oven where wood burns smartly, and whose door is left open. The caloric in this state shoots like a torrent through the ambient air, without combining with it, and even without warming it. If

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* Chemical Treatise on Air and Fire, translated into the French language by Dietrich, 1781, pa. 118 et seq.

the experiment be made during the winter, the observer will distinctly perceive the steam of his breath; which would not happen in the midst of heated air, and which does not take place effectively during the summer, because of the heat which is then really combined with the air, and communicates to it the faculty of holding in dissolution a greater quantity of water, as we shall explain in the sequel. This emission of caloric has so strong a tendency to proceed in a right line, that its direction is not changed by the current of air which is constantly moving towards the mouth of the stove, to replace that which the interior heat has dilated; even in vain do we powerfully agitate the air situated before the mouth of the stove, the rectilinear progress of the calorific rays is, notwithstanding, no more deranged than that of the solar rays.

120. Polished metals will reflect the radiant caloric according to the same laws as the light. If the mirror be concave, the action of the caloric is concentrated at its focus, and a piece of brimstone placed at that focus is instantaneously kindled; yet the mirror is not heated; but if it be put in contact with a hot body, it will take from it a part of its heat; and farther, if the surface of the mirror be done over with a little soot by being passed over the flame of a lighted candle, the caloric which falls upon the mirror then loses its radiant nature, and becomes combined with the metal, which soon becomes heated to such a degree as not to be handled with impunity. The phenomena are no longer the same when a plate of glass is made use of; the caloric, instead of being reflected, penetrates the glass which retains it in its interior, whence its temperature becomes elevated; in which heat differs from light which, in the like case, is partly reflected and partly transmitted.

121. Other experiments serve to render more evident the difference which exists, in many respects, be-

tween radiant caloric and light. When a square of glass is interposed between the stove and the focus of a concave mirror of metal, there will be formed at that focus a luminous point, but which will be destitute of heat. The same effect will have place, if the emanations from the stove be received immediately upon one of the faces of a lens; this body will analyse, so to speak, the emanations, of which the part formed of radiant caloric will remain in the lens, while the part constituted of light will produce behind the lens a focus, which will be simply luminous without being hot. Such is the substance of the observations of Scheele: they were blended in his mind with ideas relative to the nature of fire which have not a like exactness: but they were precious materials which might one day be established, as of themselves, in the edifice of the true theory of caloric.

122. Saussure and Pictet have confirmed, by new experiments, the property possessed by metallic mirrors of reflecting the radiant caloric. These two philosophers having made a ball of iron of 54 millimetres, or two inches diameter, of a strong red heat, left it to cool gradually to the point where it was no longer luminous, even in a dark place. They had previously disposed two concave mirrors, the one opposite to the other, at about 4 metres, or 12 feet distance; and then fixed the ball in the focus of the one, while an air-thermometer was held at the focus of the other. The chamber where the experiment was performed was completely close, and every precaution had been taken to remove all that might occasion accidental variations in the temperature of the air. Immediately as the ball was placed at its focus, the thermometer which occupied the other, and which previously stood at 4 degrees above zero, began to rise, and in 6 minutes arrived at 14½ degrees, while a second thermometer suspended out of that focus, at the same distance from

the ball and from the observer, mounted only to 6 degrees: whence it results, that in this experiment the reflection of the radiant caloric had elevated the temperature $8\frac{1}{2}$ degrees. To remove still farther the suspicion that this phenomenon was the effect of a light imperceptible to the eyes, Pictet has repeated the experiment, by substituting for the ball of iron a phial full of boiling water, when the thermometer situated at the other focus indicated an elevation of temperature of more than one degree*.

123. These experiments have been followed by another that is very curious, and capable of imposing upon an observer little versed in these topics, who had not been persuaded before-hand that cold cannot be reflected†. The apparatus having been disposed as in the preceding experiments, an air-thermometer was placed at the focus of one of the mirrors, and a phial full of snow at the focus of the other; immediately the thermometer descended several degrees, and then mounted again as soon as the phial was taken away: the vessel having been again placed at the focus of the same mirror, some nitric acid was poured upon the snow, and the augmentation of cold which resulted caused the thermometer to descend 5 or 6 degrees.

The first moment was that of surprise; but the explication of the phenomenon soon followed. To comprehend it, let us mentally suppress the two mirrors; then the same thing will happen to the thermometer as to the surrounding bodies, that is to say, it will yield a part of its caloric, which will be continually communicated to the snow, in virtue of the affinity by which it attracts to itself that fluid: another quantity of caloric will escape from the thermometer under the radiant form, and will distribute itself between the

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* Saussure, Voyage dans les Alpes, No. 926.

† Essais de Physique, par Pictet; Geneva 1790, pa. 81. et seq.

vessel and the surrounding bodies. Let us now restore the two mirrors to their places: then the portion of radiant caloric which had been thrown off for the snow, falling upon the mirror, at whose focus the thermometer is found, will be reflected towards the other mirror, and thence to the vessel, which will speedily absorb it; and this effect, which will be continually repeating, will determine a much more abundant and rapid emission of radiant caloric supplied by the thermometer, than that which would have obtained without the intervention of the mirrors. We have here the same advantage to diminish the heat of the thermometer, as we have to increase it, when, instead of a body colder than it, there is placed at the focus of the mirror one that is hotter; only, in the experiment of the phial of snow, the rays of caloric pursue a route opposite to that which it would have followed in the experiment of the heated ball; and it is this change of direction that imposes on the imagination, presenting to it a true reflexion of caloric under the appearance of a reflected cold *(o)*.

(o) Some curious experiments tending to illustrate the nature of radiant heat have lately been made by Count *Rumford*, Dr. *Herschel*, and Mr. *Leslie*. For a description of the experiments of the Count, the reader may be referred to his Essays and to the Philosophical Transactions: the principal experiments of Dr. Herschel are noticed by M. Haüy, in the second volume of this Treatise: but the interesting and important experiments of Mr. Leslie, the nature and conclusions from which have been recently published in this gentleman's "Experimental Enquiry into the Nature and Propagation of Heat," demand a rather detailed account in this place.

The chief of Mr. Leslie's discoveries appear to have resulted from the ingenious application of his new instrument, known by the name of the *Differential Thermometer*, and which we shall describe in a note on a subsequent part of this work, where thermometers are treated of. In conjunction with this instrument he used a variety of reflections carefully constructed of block-tin, and chiefly of the elliptical form: though sometimes he found the parabolic form convenient, especially when the reflection was made at considerable distances. The heat was given out from cubical boxes, or canisters, of plain and polished tin, with orifices at the

On Specific Heat.

124. We have not any method of estimating the absolute quantity of caloric in a body; nor can we even determine the relations between the quantities of caloric in different bodies, as we can determine those

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top, through which water of different temperatures was introduced, and a common mercurial thermometer occasionally placed in that fluid to indicate the progress of its cooling. When the apparent radiation of cold was to be tried, the canisters were filled with ice or snow. The differential thermometer being so placed that the ball containing the red liquor was in the focus of the speculum, and, the canister being filled with boiling water, the red liquor rose to a certain height, and then began to fall in proportion as the water cooled. A similar effect, though in the contrary direction, was produced by a canister filled with ice: and, in every case, the motion of the red liquor, above or below the point of equilibrium, was exactly proportional to the difference between the temperatures of the canister and of the surrounding air.

When different substances were applied to the canister while it was giving out heat, the degree of its emission suffered very singular changes. One side of the canister being coated with lamp-black, another with writing-paper, a third with crown glass, and the fourth left bare, or covered with tin-foil; the differential thermometer rose to 100, 98, 90, and 12 respectively, when those four sides were exposed to the speculum in succession. Hence the metal surface gives out heat about eight times less copiously than the other three substances. By coating the focal ball of the differential thermometer with tin-foil, it was found to receive about five times less heat from any side of the canister, than when it was exposed bare in the focus; and by coating the surface of a concave glass mirror, first with black pigment, then with tin-foil, and lastly exposing it bare to the heated body, it was found that the glass reflects very little heat, the pigment none at all, and the tin-foil ten times more than the glass. So that the metallic surface has about five times less power of absorbing heat, eight times less power of emitting it, and ten times greater power of reflecting it, than the glass.

Between the canister and the reflector a frame being placed, over which were stretched successively, tin-foil, glass, and paper: the communication of heat or cold was stopped altogether by the first, or at least, so little passed, that the differential thermometer was not sensibly affected, while the glass only stopped four-fifths, and the paper not so much. The metallic screen, too, produced this effect, however near the canister it was placed, provided the separation was perceptible. The other two sub-which exist between their densities, while the absolute density is unknown to us. We are therefore reduced to the comparing respectively the augmentations of heat received by different bodies whose temperature is

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stances interrupted the communication more and more the nearer they were placed to the canister, but always permitted a large portion of the heat or cold to pass.

Two sheets of tin, about ten inches square, were hammered quite flat and smooth, and one side of each painted with a thin coat of lamp black: the apparatus being arranged as usual, and having joined together the tin-plates, with their clear surfaces touching, they were fixed to the vertical frame, and the liquor of the differential thermometer rose 23 degrees. The position of the plates being inverted, so that the blackened sides came into contact, the liquor sunk down to zero. Either of the plates being removed, the liquor mounted again nearly 4 degrees. The case where both the external surfaces of the screen are metallic, being compared with that in which they are covered with pigment: on the one side it receives five times less heat, and this heat is propagated with eight times less energy from the other. By the joint influence of those circumstances, therefore, its effect is 40 times less; which corresponds to about half a degree, a quantity scarcely distinguishable. When the screen consisted only of a single plate, blackened on one side, the diminished effect was a mean between the receptive and the projecting powers, or 6½ times smaller than where both surfaces are painted: consequently, this enfeebled impression was equal to about 4 degrees.

Mr. Leslie having ascertained, towards the commencement of his inquiry, that bodies differ very widely in their power of projecting, absorbing, and reflecting heat, instituted a set of experiments for the purpose of ascertaining the limits of this variation. These experiments are, as yet, left unfinished, though Mr. Leslie has given several specimens of their results. Thus, the *chemical* qualities of the heating surface have a considerable influence upon its projecting power; the effect of tin being 12, iron or steel operates as 15, mercury above 20. All oxydes acquire a greater action as they recede from the metallic state. Lead being as 19; when tarnished by exposure to the air it becomes as 45, while minium is as 80. Sealing-wax and rosin are nearly equal to paper, and ice is as 85. The *polish* of the radiating surface diminishes its action, where that is not naturally great. The roughening of glass does not heighten its projecting power; but that of tin is doubled, by covering it with furrows. This singular effect cannot be owing to the greater surface which the roughened metal exposes; for the increase of surface is precisely counterbalanced by the increase of obliquity, according to a law previously established by Mr. Leslie; and moreover, it is found that the addition of cross furrows, by striating the surface in the other direction, nearly destroys elevated by an equal number of degrees, and even this can only obtain between certain limits. The following is the principle on which this comparison is founded.

125. Some observations, of which we shall speak lower down, prove, that in the mercurial thermometer, the dilatations are proportional to the augmentations of heat received by the liquid, at least from the degree of congelation to that of boiling water: it results that if a body be more and more heated, so that its temperature remains between the two limits of which we have just spoken, the dilatations of the mercury in a thermometer taken for an index of the elevation of temperature, will be also in proportion to the augmentations of heat acquired by the bodies subjected to experiment. If it be supposed, for example, that the temperature is at first at zero; afterwards, when the thermometer has risen to 10 degrees, the augmentation of heat that the body will have received will be double of that which had place, at the moment when the thermometer denoted only 5 degrees.

126. Now let us conceive that there are mixed together a kilogramme, or two pounds of water, at the temperature of 34 degrees above zero, with a kilogramme of mercury at the temperature of zero on the scale; the water will yield to the mercury a part of its

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the effect of the first operation. The *thickness* of the radiating surface greatly affects its powers of action. A thin film of isinglass produces a radiation as 26; a thicker one, as 42; but when the thickness exceeds the thousandth part of an inch, any subsequent increase does not augment its action.

The preceding, which are only a part of the curious results of Mr. Leslie's experiments, have been chiefly taken from the account of them in No. 18. of the Edinburgh Review. But those who are desirous to pursue the subject of the radiation of heat farther, in connection with the spaces through which it is propagated, the direction in which it moves, the projecting power of the heated body in respect of its position, and the connection subsisting between this action and the nature of the projecting surface, will do well to consult Mr. Leslie's work, the title of which is given at the beginning of this note. Tr.

heat until the equilibrium obtains, that is to say, until the temperature of the different parts of the mixture is arrived at uniformity; but, at this term, a thermometer immersed in the mixture would indicate a temperature of 33 degrees: from this we conclude that the water has lost the quantity of heat necessary to raise its temperature one degree, and that this same quantity of heat is capable of elevating the temperature of the mercury 33 degrees; whence it follows that the quantity required to raise the latter one degree is only the 33d part of that which would produce the same effect with regard to the water.

127. We have named *specific heats (p)* those quantities of heat that are capable of producing in bodies equal in mass, equal elevations of temperature, taking a degree on the thermometer for a term of comparison; and since these elevations of temperature depend upon the greater or less disposition possessed by bodies to unite with caloric, the quantities of caloric in question have also had given to them the name of *relative capacities for heat.* But we prefer the former denomination, as presenting a more exact expression of the idea which we would attach to it.

128. If we represent by unity the quantity of heat

(*p*) The late Dr. Black was the first who observed that the capacity for caloric is different in different bodies. Dr. Irvine, of Glasgow, afterwards investigated the subject, and Dr. Crawford published a great number of experiments relative to it in his *Treatise on Heat.* But the first set of experiments on this subject, in point of time, were probably those of Professor Wilcke, of Stockholm; though they were no where published till they were inserted in the Stockholm Transactions for 1781. Mr. Wilcke called the quantities of caloric necessary to raise the temperature of any given substances a given number of degrees, their *specific caloric;* a term which is now pretty generally employed, because the phrase *capacity for caloric* is liable to much ambiguity. The most correct table of specific caloric the translator recollects having seen, is in the article Chemistry, in the Supplement to the Encyclopædia Britannica. The term specific caloric has been used in a different sense by Seguin, who employed it to denote the *whole caloric* which a body contains. Tr.

capable of elevating by one degree the temperature of common water, we shall have for the corresponding quantity of heat relatively to mercury 0·0303; and in the same manner we may determine in units and parts of the unit the specific calorics of different bodies referred to that of water, which serves here also as the common measure, as well as in the comparison of densities.

129. Thus, in the uncertainty in which we are involved respecting the absolute quantities of heat contained by bodies, we confine ourselves to the comparison of the differences undergone by those quantities between two points of equilibrium. The ratio of these differences would give that of the absolute quantities themselves, if we were certain that the degrees of the thermometer below the term of congelation, and above the term of boiling water, might measure proportional quantities of heat lost or acquired, as accurately as the degrees between those limits. But this hypothesis is at least very hazardous, and had need be verified (before adoption) by a great number of experiments.

130. The method of Crawford, and of several other philosophers, for determining the specific heats of different substances, was similar to that of which we have spoken (126), when we took for an example mercury mixed with water: we then had respect to the particular specific heat of the vessel which had been employed, and we referred the result to the hypothesis wherein its influence would be nothing; but it still remained to estimate the heat taken off by the air and other surrounding bodies; and besides this, it was difficult to be assured whether all the parts of the mixture had acquired the same temperature. These inconveniences disappear in the use of the calorimeter devised by Lavoisier and Laplace, and which combines with the merit of precision that of being alone applicable to the case where the substances exercise a che-

mical action one upon another*. We shall describe this instrument when we have developed some principles, the knowledge of which is necessary to the attainment of a just idea of its manner of operation.

131. We will return for a moment to consider the various sensations produced in us by caloric, according to the different temperatures of the bodies which are within our reach. A substance which is in contact with our hand, and the temperature of which is more elevated than that of the hand, will yield to it a portion of its caloric depending upon the relation between the specific heats; and on occasion of the resulting sensation, we say of this substance that it is hot; on the contrary, a substance which we touch, and whose temperature is lower than that of our hand, takes from it a portion of its caloric; and on account of the sensation which is excited in us by this privation of caloric, we say that such substance is cold. Thus the temperature of our bodies is with respect to us the limit of heat and of cold; but, at bottom, there is nothing more here than a greater or less difference between two modifications which to us appear opposed, judging from the testimony of the senses: thus it happens that in proportion as the limit varies, that is to say, as the temperature of our bodies is elevated or depressed, we shall think the same substance cold, which to us had appeared hot when we were in other circumstances, and reciprocally.

Is is well known to every body that caves are found cold during the summer, and hot during the winter. The contrast of these two sensations arises from this, that the temperature of the subterraneous passages in

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* See the Memoir published by those two celebrated philosophers, among those of the Academy of Sciences for the year 1780, pa 355, et seq. where will be found the re-union of what the theory and experiments have been able to offer that is most satisfactory relative to the phenomena produced by heat.

question is nearly constant, and of an intermediate degree between those which correspond to the temperature of our bodies in the two seasons.

On the Effects of Caloric, in producing upon Bodies a Change of State.

132. The moleculæ of a body which we suppose in a state of solidity, are united by the force of affinity, which produces their mutual adherence; but this adherence is more or less weakened by the elastic force of the caloric interposed between the moleculæ, and which tend to remove them one from another. Thus these moleculæ are continually solicited by two contrary forces, whose actions balance one another: to these two forces there is joined a third, namely, the pressure of the surrounding fluids, which is opposed to the effect of the caloric to disperse the moleculæ; but the action of this latter foree is only perceptible in the passage of a body from the liquid state to that of an elastic fluid.

133. While the elastic force of caloric augments so little the distance between the moleculæ of bodies, that the affinity retains a great part of its energy*, so that the resulting adherence cannot be vanquished without

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* It may be supposed that the elastic force of caloric decreases in a greater ratio than the affinity, in proportion as the moleculæ of bodies are separated the one from the other. When the former of these forces which at first was preponderant shall have come to an equilibrium with the second, the body will cease to be dilated, unless it receive more caloric. But, it is evident that if, at this term, any force whatever should act to separate the moleculæ farther, it would experience on the part of the affinity a resistance which could not be balanced by the elasticity of the caloric, since the latter would lose more than the affinity; whence it follows that the body must remain in the state of solidity, as long as the accumulation of caloric does not pass a certain degree.

employing an effort more or less considerable, the body remains in its state of solidity; only, in proportion as it receives small additional quantities of caloric, it will pass through different degrees of dilatation, which cause its volume to vary, without sensibly changing its consistence.

134. But when caloric is accumulated in a body to such a degree as to balance the force of affinity so that the moleculæ may move freely in all directions, and yield to the lightest pressure, the body will become liquid.

At this term a remarkable phenomenon presents itself, which is, that the new quantities of caloric which come in after the instant when the liquidity commenced, are absorbed by the body as they are received, being solely employed in dissolving the new strata or beds; so that a thermometer placed in ice which begins to be resolved into water, remains stationary at the degree of zero until the ice is entirely melted.

135. Now, if it be supposed that the caloric continues to introduce itself into a body previously arrived at the state of fluidity, its effort will then be employed contrary to the obstacle which opposes it, or the pressure of the atmosphere; and when that obstacle shall be vanquished, the caloric will carry with it the moleculæ of the liquid, and will convert it into an elastic fluid.

Here the phenomenon which had previously taken place during the conversion from the solid to the liquid, is reproduced with the same circumstances, that is to say, that, during the whole time of the passage to the elastic state, the new quantities of caloric which arrive at the body are employed singly in converting the succeeding strata or plates of the liquid into elastic fluid; in such manner, for example, that the temperature of the water, in the case now under consideration, is constantly maintained at 80 degrees of the thermometer of Reaumur (212° of Fahrenheit).

136. In the return of the same bodies to their preceding state, the heat absorbed entirely reappears with their characters. Thus it is known by experience, that when a kilogramme, or two pounds of ice, is mixed with a kilogramme of water at 60°, we have two kilogrammes of water at zero, for the result of the mixture; whence it follows that the ice, in passing to the liquid state, absorbs 60° of heat, which it takes from the warm water in contact with it. Now if it be supposed that the water returns to the state of ice, it will develope during its congelation an equal quantity of heat measured by 60°, and which it will communicate to the neighbouring bodies; in like manner, when water reduced to vapour becomes liquid again, it will again put into activity all the quantity of heat which it had absorbed, and which it held concealed.

137. The name of *latent heat (q)* has been given to

(q) The very important discovery of latent heat was made by Dr. Black as early as 1757, and seems to have led the way to all the subsequent discoveries in this part of chemistry, discoveries which have made almost a complete change in the aspect of the science: for the discovery that caloric may exist in bodies while the thermometer is unable to indicate its presence, is, as Dr. Thomson remarks, "One of the strongest links in the chain of facts by which the nature of combustion was ascertained." Professor Pictet conceives that instead of the term *latent heat*, employed in the conversion of ice into water, we might perhaps use with more propriety that of *caloric of fluidity*, since there are other cases in which the caloric exists in bodies without raising their temperature: in like manner, he conceives the latent caloric in steam should be called *caloric of evaporation*.

Dr. Black never published his own account of the discovery, but he gave it every year after 1760 in his lectures, to very numerous classes of students from various parts of Europe. Among his pupils, the doctor had, about 1763, several gentlemen of Geneva, one of whom corresponded with M. de Luc. And a Swedish gentleman named Willems (from Stockholm), a student of chemistry, was much with Dr. Black, about the year 1768. None of these gentlemen ever pretended that any discovery similar to that of latent heat was known in Geneva or Sweden. In 1770 a sur-that which is employed merely in causing a body to pass from one state to another, and of which the effect becomes nothing with respect to the thermometer; and that has been named *sensible heat* which is susceptible of acting upon that instrument. Thus, when the ice becomes liquid, there is a quantity of heat of 60°, which is converted into latent heat; in such manner that it is, with regard to surrounding bodies and to the thermometer, as though it no longer existed: reciprocally, when liquid water becomes ice, a like quantity of latent heat re-assumes the character of sensible heat, it transmits itself to the neighbouring bodies, and its presence is indicated by the thermometer.

138. The sensible heat is combined, up to a certain point, with the body which contains it; in such manner, notwithstanding, that such body retains near at hand a disposition to yield a part to the surrounding bodies whose temperature is lower than its own. With regard to *latent* heat, philosophers have contemplated it under two different points of view: according to some, it is fixed in the body which changes its state, and this effect is analogous to that which is traced in the crystallisation of a salt, which appropriates to itself a portion of the dissolvant; so that this, being engaged in the crystal, loses all its appearances, and no longer retains that which characterises a humid substance. Others think that the capacity of a body which has

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reptitious publication of the doctor's lectures was made by a London bookseller under a general title; and this work gave a very distinct statement of the leading parts of the doctrine, with a full acknowledgment that Dr. Black was the discoverer. In 1772 Professor Wilcke, of Stockholm, read a paper to the Royal Society of that city, in which the absorption of heat by melting ice is described; and in the same year M, de Luc, of Geneva, published his *Recherches sur les Modifications de l'Atmosphere*, in which the doctrine is, with much less accuracy, employed to explain some meteorological facts. The reader will form a conclusion from these facts without much difficulty. Tr.

passed from the solid to the liquid state, or from this latter to the aeriform state, is found augmented. But, of two substances possessing different capacities for heat, that which exhibits the most of this faculty has need of a greater quantity of heat to keep it at the same temperature; and hence it comes, in the opinion now before us, that the ice which is resolved into water absorbs 60° of heat, forming, as it were, the complement to that which its new state requires. By a similar reason, the capacity for heat of a body which has passed from the aeriform or vaporous state to that of a liquid, or from this latter to the state of solidity, is found diminished. We are not, as yet, acquainted with any observation that furnishes a ground of preference in favour of either of these opinions.

139. We are now prepared to understand the effects of the *calorimeter:* they consist, generally, in determining the specific heat of a body, from the quantity of ice which that body, heated to a certain number of degrees above zero, is capable of melting by its contact, while its temperature is descending to zero. The quantity of ice melted in this case is exactly proportional to the heat lost by the body, and of consequence to that which it would be requisite to employ to elevate the temperature of that body the same number of degrees as it has been depressed.

Here we shall repeat that if a kilogramme of water, heated to 60°, be mixed with a kilogramme of ice, we shall have after the dissolving of the ice two kilogrammes of water at zero: for from this it results that the quantity of heat necessary to melt a kilogramme of ice gives the measure of that which would be capable of elevating the temperature of a kilogramme of water, from zero up to 60°. If, therefore, one kilogramme of another substance melt only a demi-kilogramme of ice, in passing to the temperature of zero, we must infer that its specific heat is to that of water as 0·5 is to unity. If it melt only a quarter of a kilogramme, the ratio will be that of 0·25 to 1; and thus the unit, in the present case, will be the quantity of heat, which, relatively to a kilogramme of water, corresponds to the interval between zero and 60° above that point.

This being granted, if we divide the quantity of ice which any body whatever has melted in the process of cooling down to zero, by the product of the mass of the body referred to the kilogramme, and by the number of degrees to which the primitive temperature is elevated, we shall have the quantity of ice which a kilogramme of the same body is capable of melting, by a depression of a single degree of temperature. Then multiplying the result by 60, we shall have the quantity of ice which would have been melted, if the temperature were suuk from 60° to zero, which will give at the same time the specific heat of the body referred to that of water, taken for unity.

The calorimeter is a kind of cage, the interior of which is divided into three cavities included the one in the other. The interior cavity, or that nearest the centre, is formed of a grating of iron wire, on which the body rests whose specific heat it is wished to ascertain; the succeeding or middle cavity is destined to contain a quantity of pounded ice, which should surround the interior cavity, and is to be melted by the heat of the body subjected to the experiment; the third or exterior cavity receives another quantity of ice, the effect of which is to arrest the heat of the air and of the surrounding bodies. At the moment of the experiment, the temperature of the ice must be at zero; and it will be well if that in the outer apartment is not below that term. The quantity of water produced by the melting of the ice contained in the middle cavity runs off, by means of a cock, into a vessel situated under the machine; and it is pretty certain that this water arises solely from the action of the heat lost by the body submitted to the experiment, since the ice which is in the same cavity is preserved by that which surrounds it from the impression of all extraneous heat. The air and the neighbouring bodies can only act upon the stratum of ice situated on the outside, and the water which, in this case, is produced by their action, flows off by means of a tube which receives it separately *(r)*.

140. We will render sensible, by an example, the manner of submitting to computation the result of an observation. Let us suppose that a body weighing 7·7 kilogrammes, heated to 78° above zero, has melted 1·1 kilogramme of ice, in passing to the temperature of zero; if we divide 1·1 by the product of 7·7 and of 78, we shall have 0·0018 kilo. for the quantity of ice which a kilogramme of the same body would be capable of melting, in cooling one degree. This result multiplied by 60 will give 0·1080 for the specific heat of the body referred to water.

If the body is itself a liquid, it must be inclosed in a vessel of which we have determined the specific heat.

(r) This method, by means of the calorimeter, appears by far the most simple of ascertaining the specific caloric of bodies; and, provided we can be certain that all the melted ice or snow falls into the receiver, must likewise be the most accurate. But if we form our judgment from an experiment of Mr. Wedgewood, we shall be ready to conclude that this does not happen: for he found that the melted ice, so far from flowing out, actually froze again and chooked up the passage. We should rather doubt, however, whether this circumstance would attend *every* experiment; since we can hardly bring ourselves to believe, that such eminent men as Laplace and Lavoisier would not scrupulously regard the particularities accompanying their use of this instrument. The result of Mr. Wedgewood's experiment is, nevertheless, properly held out as a caution not to place an implicit reliance on the conclusions furnished by this instrument. It may also be added that the external air ought never to be below 32° of Fahrenheit (zero of the centigrade), nor above 41° (5° of the centigrade). In the first case the ice in the middle cavity might be cooled too low; in the last, a current of air would flow through the machine and carry off some of the caloric. Tr.

Then, we must subtract from the quantity of ice melted the part which is owing to the effect of the vessel, which will give the quantity obtained by the cooling of the liquid: the remainder of the operation will be the same as for solid bodies.

141. We have said that the pressure of the surrounding fluids is combined with the affinity to balance the force of the caloric, which tends to scatter the moleculæ of bodies, but that the effect of this pressure is only sensible in the passage of a body to the elastic state. If after having placed under a receiver a vessel which contains a fluid, we take away the pressure of the air by means of an air-pump, the liquid will be converted into vapours by a much lower temperature than in the case where it is found exposed to the free air. It results indeed from the experiments of Prony, that we may carry the vacuum so far as to determine the passage of water to the elastic state, by a temperature which is scarcely elevated above zero, while this liquid requires a heat measured by 80° to arrive at the elastic state under the pressure of the atmosphere. It is a consequence of the same principles, that if we ascend a mountain with a vessel full of water, the column of air becoming shorter as we rise, the diminution of pressure which results may be sufficiently sensible to give place to the conversion of the liquid into an elastic fluid.

142. This gradation in the passages of a solid body, first to the state of liquidity, and then to the state of elastic fluidity, has been viewed and presented during a long time by philosophers only in an imperfect manner. They merely considered in these transitions the action of fire, which would commence by dilating a body, afterwards would put it in a state of fusion, or would convert it to a liquid, and finally would be reduced into vapours. The modern chemistry has completed the picture of the phenomena, by bringing

together, under the same point of view, the actions of those different forces, which incessantly struggle one with another, and which, according as the one or the other predominates, determines all the transitions between the state of a body of which all the moleculæ form a solid and compact mass, and the state of the same body, attenuated to the point of becoming impalpable and of disappearing from our sight.

143. This point of view may also serve to present, under a new light, the theory of caloric, in this that it brings in connection phenomena which the generality of men do not class together, and which indeed have been distinguished in their language: such as, for example, on the one part, the conversion of solid iron to liquid iron, by the action of fire, or its return to the former state by cooling: and, on the other part, the melting of frozen water, or the passage of liquid water to the state of ice. These phenomena differ only by the circumstances, or by the greater or smaller quantity of caloric employed in producing them; so that it is correct to say that the liquefaction of iron by heat is the *thawing* of iron, and that its return to the state of consistence by cooling is the *congelation* of iron. The philosopher is thus accustomed to consider under the same aspect, to accommodate mutually and connect in his conceptions, those effects, of which the one is the faithful image of the other.

144. The results of the action of caloric in balancing the affinity of the moleculæ of a solid body, at the point of carrying on at first the transition to the liquid state, and finally of drawing along with it the moleculæ under the form of vapours, are limited by observation to a certain number of substances. But they have received from the theory a generality which cannot well be refused them, and the consequence has thence been deduced, that all natural bodies are susceptible in themselves of the three states of which we have

spoken, and that a great part of these bodies only appear invariable for want of the power of acquiring or losing the quantity of caloric sufficient to determine their passage from one state to the other. The greatest difference which can exist between the temperature of climates where the most lively heat of the sun is experienced, and of those which the great obliquity of its rays leave exposed to the most severe cold, produce not very sensible effects, except with regard to the water which constantly retains its liquidity in regions near to the equator, and loses it only by intervals in our climates, while towards the poles the enormous piles of ice can only escape from the constant action of the cause which has hardened them, by moving on, as so many floating mountains, to be thawed in the seas of the temperate regions.

145. In this respect the power of art greatly surpasses that of nature. We shall see when speaking of water to what extent the action of artificial cold has been carried, beyond the point which corresponds to the congelation of that liquid. But it is by the effects of heat in going back to the opposite limit, that the majority of transitions to a new state have been determined. By concentrating the action of the solar rays in the focus of a burning-glass, we have succeeded in melting bodies which had hitherto resisted all the action of the fire of our furnaces, and in volatilising gold and other metallic substances.

146. It might seem that this were the ultimate effort of art in augmenting the intensity of the action of caloric. But the modern chemistry has gone much farther, by substituting for the celestial fire an ordinary fire, which is supplied with vital air, its element, in a state of purity: by means of this flame, animated by a current of that gas, metals have been volatilised with more promptness and facility than in the focus of a lens; and some metals, such as copper, which were only

oxydated by the latter means, have been entirely volatilised by the former. Several very refractory stones have been melted, others have undergone only the first degrees of softening, and of this number are the pure quartz, and some gems.

147. But these limits are still very distant from those which it is requisite that the forces of nature or of art should be capable of attaining, that the three degrees of solidity, of liquidity, and of elastic fluidity, may be realised in relation to every substance; so that many bodies may be considered, in the actual order of things, some as being in the state of permanence; others as being, at most, susceptible of passing to one of the states nearest to that in which it exists habitually. Thus, we cannot presume that we shall ever have a method of volatilising quartz, or of congealing alcohol and ether; and the atmospheric air is placed, for our advantage, unchangeably in the class of elastic and invisible fluids.

148. Another fact, connected with those which we have expounded, is that all bodies that are dilated, whatever be the cause of that dilatation, takes away caloric from the surrounding bodies; and on the contrary, all bodies whose volume is contracted, whatever, in like manner, be the cause of that contraction, yields some of its caloric to the surrounding bodies. When we dilate the air contained in the receiver of an air-pump, by the usual operations of that machine, a thermometer placed in the midst of such air falls at the same instant; if, on the contrary, the air in the receiver be compressed, the thermometer will be seen to mount. Commonly these variations of the thermometer do not exceed one or two degrees; but it appears that the quantity of heat absorbed or disengaged in these experiments, greatly surpasses that which we should conclude from the indication of the thermometer simply; for it ought to correspond to a

difference of temperature much greater with regard to the air than in relation to the instrument, the mass of which considerably exceeds that of the air; and besides, the neighbouring bodies restore in part the heat which has disappeared, or take away part of that which is disengaged; which tends farther to diminish the effect indicated by the thermometer.

149. Here we come again to a disagreement of opinions among philosophers, of whom some think that the quantity of heat which disappears in the dilatation, is combined with the body, and that that which reappears in the condensation is disengaged from the combination; while others, to explain the same effects, suppose that the capacity for heat augments when the body is dilated, and diminishes when it is condensed. In the case of a dilatation always increasing the capacity for heat, according to this hypothesis, would itself increase more and more; and it has been even concluded that a vacuum, though it were merely a simple space, would have a greater capacity for heat than that of an equal volume of air, however dilated that fluid might be; that is to say, that a vacuum would give the *maximum* of this kind of variations.

150. The preceding remarks may assist in the elucidation of several well-known effects.

If, for example, we wrap a piece of fine linen about the ball of a thermometer, and moisten this linen with ether, then, agitating the thermometer in the air, to renew the points of contact, and facilitate evaporation, which, as will be seen in the sequel, is nothing else than a species of rarefaction, we shall cause the liquor in the thermometer to descend very perceptibly; hence again, the sensation of cold which is experienced during the evaporation of a drop of spirituous liquor that has been let fall upon the hand. It will be equally easy to explain a fact which presents a species of paradox, and which takes place, when at the first stroke of the solar rays, that is to say, at the re-engendering of the heat, the thermometer falls during an instant. This effect is occasioned by this, that the small quantity of dew with which the thermometer is moistened, being evaporated by the action of the sun, the thermometer will give out a portion of its caloric. We know, on the other hand, that when a bar of hot iron is struck, every stroke of the hammer, by driving the moleculæ nearer together, causes jets of radiant caloric to shoot forth, which become sensible by the impression of heat which they excite all around them. These different effects have been enunciated in that species of axiom that *bodies are the* SPONGES of *heat.*

151. Many philosophers have attempted to explain, from the same principles, the developement of heat which arises from the friction of bodies. They would consider this friction as a species of hammering which tends to condense the parts on which it acts, and press or squeeze out more or less of the caloric contained in bodies, according as the moleculæ may be found more or less forced towards each other.

We shall now proceed to re-examine the various states the gradation of which we have established generally, with a view to consider them successively in relation to different particular bodies.

Dilatations of various Solids.

152. Philosophers have sought to determine the dilatations of several solid substances, especially those with regard to which that determination would become interesting through the precision which may result as to certain operations in the arts; thus it has been found that, for every increasing degree of Reaumur's thermometer, iron is dilated about $\frac{1}{75000}$ of each of its dimensions, copper $\frac{1}{43000}$, and glass $\frac{1}{10000}$.

153. To estimate the dilatation of one of the surfaces of a solid, when we know the ratio of dilatation of the substance of which it is composed, we must multiply the fraction that represents this ratio by the number of degrees the temperature has been elevated, and take the double of the result; and to value the dilatation of the whole volume, we must triple the same result: if, for example, a mass of iron be dilated by passing from a temperature marked by 10° on Reaumur's thermometer to that of 15°, making an elevation of 5 degrees of temperature, we multiply by 5 the fraction $\frac{1}{75000}$, which expresses the ratio of the dilatation of iron; and by tripling the result we have $\frac{15}{75000}$ or $\frac{1}{5000}$, shewing that the body is dilated by a quantity equal to $\frac{1}{5000}$ of its volume. Mathematicians will readily see that this method is reduced to considering the body as a parallelopiped, whose solidity would be the product of the three dimensions of that body, and subsequently enquiring into the augmentation of such solid, by making each dimension to vary according to the given law of dilatation, and rejecting from the result the quantities that are affected with powers exceeding the first degrees. The error produced by this omission is considered as nothing with respect to this kind of results. It is supposed in these evaluations, that the degrees of dilatation sensibly follow the variations of temperature; an allowable supposition in the present case, since the bodies under consideration have a moderate temperature, and are far from fusion, where the action of the caloric acquires so great a preponderance over the affinity, that the dilatation assumes a much more rapid march than that of the temperature.

154. S'Gravesande contrived the following experiment to prove the dilatability of metals by heat. He made use of a plate of copper hollowed into the form of a ring, and of a globe of the same metal, the dia-

meter of which was precisely equal to that of the opening of the ring, so that when this latter was at the ordinary temperature, the globe would pass through its opening without leaving a perceptible interstice: afterwards, when this globe had been heated, it was sustained by the ring, in whatever position it was placed upon it.

155. The dilatability of glass is proved by the aid of an experiment, the result of which always excites the surprise of those who behold it for the first time. Take a glass tube, of a small diameter, terminated by a ball about the size of an orange; fill the ball and a part of the tube with a coloured liquor, and mark on the tube the height at which it stands; immerse the ball in a vessel full of water near boiling, and then draw it out again: at the moment of the immersion the liquor in the tube descends precipitately by a considerable quantity; but it rises again a little higher than the mark made upon the tube, as soon as the ball is drawn out of the hot water. In this experiment the heat, which is communicated at first to the glass, dilates the parts, which augments the capacity of the ball, and causes the liquor to descend; the ball being afterwards taken out of the hot water, and again placed in contact with the air, contracts, and the liquor, which has previously acquired a small quantity of heat, rises a little above its first level.

156. The substance which is fabricated in potteries for domestic uses, being in itself a bad conductor of heat, especially if its texture is compact and close, there will result an inconvenience which will become more or less sensible, when we expose these vessels to the action of heat. This fluid, in consequence of the slowness with which it distributes itself, accumulates at the places which offer it the most free access, and tends to produce there a dispersion of the moleculæ;

and, supposing that by due precautions those ruptures are avoided which would render the vessel unserviceable, there will be made on its first exposure to the fire a multitude of little flaws, which are announced by a kind of crackling, and which soon become apparent to the eye, by forming a sort of network upon the surface of the varnish with which the vessel is glazed. A more loose and porous texture would obviate this inconvenience, but the vessel would then become more weak and easily broken; so that we can only obtain one of these two qualities, solidity and resistance to the action of fire, at the expense of the other.

157. The influence of caloric upon the dimensions of bodies is shewn in a multitude of other facts, the observation of which is familiar to us. A sensible change of temperature alters the degree of tension of the cords in musical instruments, following a different relation from that which had been established by the tuner, and depriving the tones of that mutual adjustment without which harmony cannot exist.

158. It is known how the dilatation and the condensation of metals, by the variations of temperature, affect the regularity in the motion of clocks, by augmenting or diminishing the length of the pendulum rod. By a very ingenious mode of proceeding, philosophers have been able to turn this cause of irregularity against itself, and to make these anomalies give birth to constancy and uniformity. The process consists, generally, in combining with an iron pendulum rod, another metallic body, which is ordinarily of copper, and to dispose the whole in such manner that when the iron bar to which the bob is suspended lengthens or shortens, the copper experiencing similar variations in a contrary sense, establishes an exact compensation, the effect of which

is to retain the centre of oscillation (*s*) constantly at the same height.

On the Thermometer.

159. The dilatations of liquids have given rise to a valuable instrument in the hands of the philosopher, which is employed in a variety of experiments, and which has even obtained almost a general use through the interest with which all men consult it. This instrument is the thermometer which serves to measure the degrees of heat. Previous to its invention philosophers had only uncertain and confused indications of the variations of temperature; they were limited to the respective comparison of the most severe winters and the most scorching summers, from certain general effects which would present an approximation almost as vague as the terms cold and hot are in themselves. The thermometer enables us to keep a faithful and detailed journal of the different seasons in every year, and the gradual effects of their temperature.

160. This instrument, the first idea of which is attributed to a Dutchman named Drebbel, was at first very imperfect, as are the majority of human inventions in their origin. It consisted of a glass tube, terminated at one end by a ball, and open at the opposite extremity. It was immersed by this same extremity in a coloured liquor; then, by applying the hand upon the ball, to heat and dilate the interior air, a portion of that air was disposed to escape through the liquor; in such manner that when the hand was afterwards taken from it, the remaining air being con-

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(*s*) The principal contrivances to ensure this compensation in pendulums are described under the article P[illegible] most of our Encyclopædias: those who have not op[illegible] such voluminous works are referred to vol. II[illegible] 267—273. Tr.

densed by the cooling, permitted the liquor to introduce itself to a certain height by the pressure of the exterior air. The instrument was then found in a state fit for use, and it was the dilatation of the interior air, or its contraction, in virtue of the variations of temperature, which, by causing the descent of the liquor suspended in the tube, or by permitting it to rise, indicated those variations *(t)*. But it is readily comprehended that this instrument, the motions of which were complicated at once of the effects of the thermometer and those of the barometer, could only give equivocal indications.

161. Ere long, however, philosophers employed themselves in perfecting this first unrefined sketch, and in bringing the instrument to be no more than a simple thermometer. Such was that which has been named the *Florentine thermometer*, and which consists of a glass tube, terminated likewise by a ball, but which is sealed hermetically at the top, after being filled with a coloured liquor up to about the middle of its height. Afterwards this tube is properly attached to a graduated plate, and the dilatation or contraction of the liquor is estimated by the number of degrees run over. But as all was arbitrary, both in the construction of the instrument and in the divisions of the scale, each thermometer could only be compared with itself, and

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(*t*) The first description of a thermometer ever *published* is that of Solomon de Caux, a French engineer, in his book *Des Forces Mouvantes*, printed in 1624, in folio; but written prior to that period; for the dedication to Louis XIII. is dated 1615, and the privilege granted by that monarch is dated 1614. This thermometer acted by the dilatation of air contained in a box, which, pressing it against water, forced it to rise in a tube. The similar invention of Cornelius Drebbel, of Alcmaer, was devised, it is generally said, while he was in the court of James the first of England, which must have been between 1603 and 1625. So that at this distance it is not very easy to determine which of these two was the prior invention, or whether they were independent of each other. Tr.

two thermometers thus constructed would not mutually agree, but would speak different languages.

162. This was succeeded by various attempts to render thermometers comparable; and at length Reaumur attained this object in a more advantageous manner than had been accomplished before his time*, by means of a construction in which the sagacity of that celebrated philosopher is displayed, and which merits an elucidation, even after better instruments have been invented. Reaumur, in devising his thermometer, proposed to himself to fulfil three conditions: the first, that the graduation should commence from a constant term where the zero of the thermometer should be placed; the second, that the degrees might have a determinate relation, with the capacity, both of the ball and of the part of the tube situated between that ball and the point where the zero is placed; the third, that the alcohol which was employed might have a known degree of dilatability to which one could always refer it. He had to choose between two constant terms, which before that time had been remarked, namely the heat of boiling water, and the cold produced by the congelation of water (u). He decided in favour of the latter, being that which seemed to furnish the natural limit between heat and cold, and he chose for the determination of it the instant of the artificial congelation of water by the aid of a mixture of ice and sea-salt. Philosophers afterwards substituted for this term that of melting or thawing ice, which is more invariable.

Reaumur made use of common water to graduate his thermometer. He first filled the ball and a part of the tube with this water, and arranged it so that the

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* Mem. de l'Acad. des Sci. 1730, pa. 452 et seq.

(u) These points were first proposed by NEWTON. See Gregory's Mechanics, vol. II. pa. 444. TR.

quantity of water employed was a thousand times as great as that which could be contained in a very small measure taken for unity. Having marked zero at the place where the water stood at rest, he prepared himself to trace the degrees, commencing with those of condensation. With this view he took out of the tube such a quantity of water as would exactly fill a measure containing the unit a certain number of times: supposing that this measure was of 25 units, there would obtain, in this case, 25 degrees of condensation in the thermometer. He made use of the elementary measure to obtain these degrees, in such manner that every elevation of the water within the tube, procured by the pouring in of an elementary measure, would determine the measure of a degree. But in this second operation, Reaumur substituted mercury for water, since it did not adhere to the glass, whence there resulted a greater precision. The mercury by falling to the bottom of the ball caused so much of the liquor contained in the tube to rise. By means of this process Reaumur carried the graduation to 80° above zero. He preferred the graduating of the tube thus, by making equal quantities of liquid enter it successively, rather than to continue the division from the known magnitude of a single degree, that he might have nothing to fear from the interior inequalities of the tube and the variations of its diameter.

The graduation being once established, Reaumur emptied the tube, and poured into it alcohol up to the height of 4 or 5 degrees above zero; then he immersed the ball in water which contained a vessel of tin encompassing artificial ice. At the moment when the water commenced congelation, Reaumur observed the point where the alcohol stood, and according as this liquid was found a little above or below zero, he took from it, or added to it, till its height in the tube coincided exactly with the point marked zero.

It is obvious from these details that for one degree of heat the alcohol dilated itself by a quantity equal to the thousandth part of that which, at the moment of the congelation, filled the ball and the part of the tube comprised between that ball and the point zero.

The operation would be limited to the processes we have described, if all alcohol had the same quality and the same dilatability. But as these advantages are not attainable, it became necessary to determine the quantity of dilatation, of which the alcohol employed in the construction of the thermometer was susceptible. The following is the way by which Reaumur was conducted to this determination. Having plunged at several trials a tube filled with alcohol to a certain height in water, which continued heating more and more till it reached the state of ebullition, he remarked that when the bubblings which the heat had excited in the alcohol itself were appeased, after the tube had been taken from the water, the alcohol was always found higher than previous to the immersion; but this dilatation only obtained unto a certain term, beyond which, as soon as the ebullition had ceased, the liquor stood again at its level. He regarded as a fixed term for each kind of alcohol, that dilatation which was the greatest that the liquid could experience by the heat of boiling water, when it did not itself boil; whence it resulted that there was, in relation to a given alcohol, a constant ratio between the volume of the liquid which corresponded to the term of congelation, and that of the same liquid dilated as far as it could possibly be without boiling. This ratio was the greatest for rectified alcohol, and diminished when the alcohol was weakened by a mixture of water. Now Reaumur had assumed the ratio of 1000 to 1080, which could only agree with alcohol a little diluted with water; and it was requisite to enquire tentatively what degree of mixture produced that ratio.

Hence it appears that Reaumur only employed the heat of boiling water secondarily, and that the 80th degree on his thermometer was necessarily situated lower than on the ordinary thermometer, since it required a less heat than that of boiling water to bring the alcohol to the degree where it is at the point of ebullition.

The construction of which we have been treating was generally received. Hardly any thing was more spoken of than Reaumur's thermometer; and this produced so familiar and intimate a connection between the names, that even to the present day the thermometers commonly used in France are called *thermometres de Reaumur*, although they are not made conformably to his method.

163. The motion of the fluid in these latter thermometers is referred to two fixed terms, of which the one that serves for the point of departure is not precisely the temperature at which water congeals, as in Reaumur's thermometer, but that at which ice thaws; the other which gives the opposite limit, is the heat of boiling water. The tube is chosen of the most regular calibre possible, and the distance comprised between the two fixed terms is first divided into 80 degrees; the division is then continued similarly below zero. In the thermometer, which is called *centigrade*, the distance of which we have just spoken is divided into a hundred equal parts.

This method combines with the merit of great exactness that of simplicity, in so far that it solely refers the construction of the thermometer to the very cause of the variations in that instrument, and to the two epochs where the water, by suddenly assuming a new form, apprizes the philosopher of the existence of the fixed point which he is endeavouring to lay hold of. We ought to observe, on this occasion, that the pressure of the air has no perceptible influence upon the first limit, which is the degree of melting ice, while it is necessary to have respect to that pressure in determining the opposite limit; since, in proportion as the water is more or less compressed, ebullition occurs at a higher or a lower temperature. The pressure has been chosen which corresponds to an altitude of 29·9 English inches in the barometer, because this is the mean pressure, or that which commonly has place on the sea coast.

It is now pretty manifest that the two limits being the same in different thermometers constructed according to these principles, and the degrees of the scale on all such thermometers being parts proportional to the distance between the two limits, the indications furnished by the motion of the liquor correspond with one another, whatever the distance in question may be. The graduation will thus become, as it were, a language of communication between all thermometers; so that if two of those instruments placed, the one at Paris the other at Amsterdam, indicate the same degree, we may be certain that the temperature is the same at the two places; and that, if they mark different degrees, each of them will tell us precisely what the other would if it were in the same position.

164. The choice of the liquor is an important circumstance, whether for giving to every thermometer a progress more conformable to that of the temperature, or for producing a more exact agreement between different thermometers. During a long time alcohol was employed; but, supposing we were able, by a process similar to that of Reaumur, to place this liquid always in a state where its extreme dilatation would retain the same ratio with that which should answer to zero, there would remain an inconvenience to which sufficient attention was not originally paid; and which consists in this, that the progressive dilatations of the liquor mark degrees perceptibly un-

equal for equal variations of temperature. The experiments of Deluc have served at the same time both to demonstrate this inequality, and to render evident the advantage possessed by mercury, of being among all known liquids, that which approaches the most to the state of undergoing dilatations exactly proportional to the augmentations of heat, at least between zero and the degree of boiling water. One example will suffice to give an idea of the manner in which the celebrated Genevese philosopher was conducted to this result.

Suppose that in an apartment whose temperature is 6° above the zero of the thermometer divided into 80 parts, we mix with a certain mass of water possessing that same temperature a new equal mass of water heated to 75°, and that we agitate the water greatly; the excess of the heat of the hottest water above that which was less heated will be equally divided between the two masses of water; in such manner that the temperature of the mixture, when arrived at uniformity, will be equal to the 6° that was common to both masses, *plus* the half of the difference 69° between the two temperatures, that is to say, it will be $40\frac{1}{2}$°. If, therefore, we then plunge into the mixture the thermometer which has served to determine the particular temperatures of both masses of water, and if the liquor of that thermometer should stand at $40\frac{1}{2}$°, we should conclude that its dilatation is proportional to the augmentation of heat. It is to trials of this kind that Deluc has subjected mercury, and he has found that it sustained them in a satisfactory manner, except that it remained *a little* below the point where it should be to indicate the true temperature of the mixture. But, on comparing the progress of the alcohol with that of the mercury, between the same fixed points, it is observed that in general the former of these liquids is always elevated to a less height than the other; and this single observation suffices to prove that the indications of the mercury are those which approximate nearest to the truth. Hence it is desirable that the use of mercurial thermometers may become general, since they alone are comparable. The thermometer of alcohol should only be employed in the case where it is wished to make observations with an artificial cold greater than that of 32°, which determines the congelation of mercury. With regard to this latter effect we shall reserve the exposition of it till we treat of the congelation of water, which is accompanied by circumstances, the contrast of which with those presented by mercury in the same case, have induced us to reunite the two phenomena under the same point of view.

165. Some philosophers have thought that when air is left between the liquor of the thermometer and the top of the tube, the dilatations of that fluid by the action of heat would be opposed to those of the mercury or of the alcohol, an obstacle which would affect the regularity of these latter. Yet observation shews that this obstacle is of no force, and the theory alone indicates that it ought to be so: for the air in this case can only act upon the liquids as a compressing force; but it is known that liquids present a sensible resistance to compression, and this resistance obtains equally at all temperatures; while, on the contrary, fluids permitting themselves to be compressed with much facility, it will be the mercury or the alcohol which will compel the air to contract and to surrender its place (*w*).

166. In the words of foreign philosophers [M. Haüy obviously means foreigners with respect to France, as the

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(*w*) It has been usual when *fluids* have been distinguished from *liquids*, to say that the latter are such substances as impart moisture to other bodies immersed in them, or applied to them; and in this sense mercury is not a *liquid*, but simply a *fluid*. M. Haüy, however, instead of this distinction has generally, though not universally, adopted another, in which the term *liquidity* is restricted to those which have been commonly deemed incompressible fluids, and that of *fluidity* to those which are compressible and elastic. The distinction between *aeriform* or *permanently elastic fluids*, and *vapours* or *non-permanent elastic fluids*, is made by M. Haüy at par. 229 following. TR.

English, the Germans, the Russians, &c.] we frequently meet with the results of observations relative to two other thermometers, of which it will not be useless to give some account in this place, that it may be in the power of every reader to translate their language into that of the thermometer in use among us.

The first is the thermometer of Fahrenheit, which is mercurial, and has for fixed terms the degree of congelation produced by the ammoniacal muriate, and that which answers to the heat of boiling water. The interval between these two terms is divided into 212 parts; the 32d degree coincides with the zero of Reaumur's thermometer, which gives 180° from this point up to that of boiling water. Thus, 9 degrees of Fahrenheit's thermometer are equivalent to 4 degrees of the thermometer divided into 80 parts, and to five degrees of the centigrade thermometer; which (duly regarding the position of the freezing and boiling points) will suffice to institute the comparison between the results given by the two instruments.

167. The other thermometer is that of Delisle, in which that philosopher likewise employed mercury; it has only one fixed term, namely that of the heat of boiling water, where the zero was placed. The degrees of condensation below that term were the ten-thousandth part of the capacity of the ball and of that of the tube which terminated at the zero. The degree to which the temperature of thawing ice was referred, and which corresponds to the zero of Reaumur's thermometer, was the 150° of the descending scale upon the thermometer of Delisle: whence it follows that 15° of this thermometer answer to 8° of the thermometer divided into 80 parts, and to 10° of the centigrade thermometer; so that with respect to the latter the ratio reduced to its greatest simplicity is that of 3 to 2. (*x*).

(*x*) In the brief account of the interesting deductions made by Mr. Leslie from his ably conducted experiments relative to heat, given at note

The multiplied researches undertaken by philosophers, with the view of perfecting the thermometer, would alone suffice to prove the merit and importance of this instrument. It has served to unveil to us a multitude of interesting facts. Its presence is necessary in an infinity of experiments to compare the temperatures of bodies which are employed, or determine the changes which have happened in the temperature they possessed originally. It is

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(o) par. 199, a reference was made to that philosopher's *differential thermometer*, which shall therefore be described here. It consists of two tubes, each terminating in a small bulb of the same dimensions, joined by the blow-pipe, and bent in the form of a U, a small portion of dark coloured liquor having previously been introduced into one of the balls. The fluid best adapted to the purpose is found to be a solution of carmine in concentrated sulphuric acid. By managing the included air with the heat of the hand, this red liquor is made to stand at the required point of the opposite tube. This is the zero of a scale fastened to that tube, and divided into equal parts above and below that point. The instrument is then fixed on a stand. It is manifest that when the liquor is at rest, or points at zero, the column is pressed in opposite directions by two portions of air equal in elasticity and containing equal portions of caloric. Whatever heat, therefore, may be applied to the whole instrument, provided both bulbs receive it in the same degree, the liquor must remain at rest. But if the one ball receives the slightest excess of temperature, the air which it contains will be proportionally expanded, and will push the liquid against the air in the other bulb with a force varying as the difference between the temperatures of those two portions of air: thus the equilibrium will be destroyed, and the fluid will rise in the opposite tube. The degrees of the scale through which it passes will mark the successive augmentations in the temperature of the ball which is exposed to the greatest heat; so that this instrument is a balance of extreme delicacy for comparing the temperatures of its two scales.

When thermometers are contrived to measure very great degrees of heat by the expansions they produce in substances, or, on the contrary, the expansions corresponding to different temperatures, they are characterised by the name of *pyrometers*; descriptions of the principal of them being given in most of our Encyclopædias. A very good history of thermometers is given under that word in Dr. Hutton's Mathematical and Philosophical Dictionary. The reader may likewise consult the translation of Ozanam's Recreations, vol. iv. for some useful particulars; and the second volume of Gregory's Mechanics for an account of the steps taken by the committee of the Royal Society of London relative to the adjustment of the fixed points of thermometers. Tr.

often useful to have recourse to its indications to know the heat that is proper for the chamber of a sick person, the water of a bath, a stove, or a hot-house, in which we would either promote the vegetation of indigenous plants, or preserve foreign plants. It is, so to speak, a social instrument, which every one may at his pleasure interrogate respecting so important a point as the variations experienced in the temperature of the fluid in the midst of which we live; and when these variations extend themselves much beyond the ordinary limits, the indications of the thermometer become of general interest; the recital made by each person of what he has observed on his own instrument is, at such seasons, one of the subjects which takes the most prompt possession of familiar conversation.

As to the dilatations of liquids, by the accumulation of caloric, we shall reserve them to be spoken of when we are treating the properties of the air.

On Combustion.

168. Although the theory relating to the manner in which caloric acts in combustion appertains properly to chemistry, yet we cannot willingly terminate that which regards this fluid, without giving some such details on this subject as are connected with the history of Natural Philosophy. Combustion presents generally the aspect of a body that is dissipated in producing what are commonly called *heat* and *light*. In the vulgar language *fire* and *combustion* are almost synonymes the one of the other; but in the idea of the ancient philosophers, fire was the agent of combustion. They regarded it as a fixed principle in bodies, the extrication of which produced the dissipation of the moleculæ of the substance containing it; and it was to the same principle that Stahl gave the name of *phlogiston*. The manner in which the philosophers who

adopted the doctrine of that celebrated man explained combustion was the more seducing, as the cause on which they made this phenomenon depend was presented under the appearance of a mechanical cause. The moleculæ of elementary fire were lodged in those of the body as in so many little covers or wrappers, where they experienced a compression similar to that of a bent spring. In combustion, the fire escaping in consequence of its expansive force, the particles by which the deflagration is commenced impress upon the neighbouring particles a stroke or jolt which occasions their rupture by the unbending or expansion of the fire which they concealed; and thus the commotion, and, by a necessary consequence, the conflagration would be communicated from one particle to another through the whole mass. The air would contribute to maintain and to accelerate the action of the fire, by reacting contrary to it, and by opposing to its dissipation an obstacle which would concentrate its action into a smaller space, and thus augment its energy.

169. But the discoveries of modern chemists, and especially those of the illustrious Lavoisier, have entirely changed the point of view under which combustion should be contemplated. They have demonstrated that this combustion consists in a combination of the proper moleculæ of a body with those of the oxygen which that body takes up from the surrounding air, accompanied by the disengagement of light and of caloric, which retained the oxygen in the state of an elastic fluid. This doctrine has caused phlogiston to disappear, as being at least useless; and the atmospheric air, which was regarded as a simple stimulant, with respect to combustion, furnishes the principle which is the chief and immediate agent (y).

(y) The subject of combustion is a very difficult one, respecting which opinions are still afloat: the theory of the eminent yet unfortunate Lavoisier, though adopted by M. Haüy, and indeed by the generality of chemists both continental and English, is far from satisfactory. It is true, that he has corrected the errors of several of his predecessors, and has advanced one very important step before them; but many additional steps are requisite to render the theory complete. It explains satisfactorily why the burning body gradually wastes away during the process of combustion; but it furnishes no explanation of the constant emission of heat and light, though this is a circumstance quite as worthy of attention as the wasting of the body. Indeed the French chemists have attached a new meaning to the term *combustion*, having made it stand for the general *combination of a body* with oxygen: but Dr. Thomson of Edinburgh, who has lately extended and improved the theory of Lavoisier, employs the term in the sense usually affixed to it by the generality of mankind. When a body undergoes combustion, two things, as this philosopher remarks, take place. 1. The body gradually wastes away, and often disappears altogether; it being then said to be *consumed* or *burnt*. 2. During the whole of this process it emits *heat* and *light*; the heat and light thus emitted are usually denominated *fire*; and the waste of the body is considered as the effect or consequence of its combustion. Hence, a true theory of combustion must satisfactorily account for these two things; namely, the change which the body undergoes, and the emission of heat and light which accompanies this change.

Dr. Thomson thinks that, as far as combustion is concerned, bodies may be arranged under three classes: viz. 1. Combustibles. 2. Supporters of Combustion. 3. Incombustibles. In his theory it is supposed that the light of combustion is furnished by the combustible body, and the heat by the oxygen of supporters; but that products convert combustibles into products by mere oxygenation without combustion. The leading positions are, that light is originally an ingredient of combustibles, and heat of oxygen. As the author completely establishes the facts on which his reasoning rests, there can probably be only one plausible objection urged against it. Why is not the caloric of the oxygen separated when that gas combines with bodies destitute of light? It is incontrovertible that caloric is emitted on many occasions, when no light *appears* with it. However, should it be a fact that the matter of light is chemically combined with all bodies which emit heat, though it does not fly off until the heat becomes great, a thing which is not improbable, Dr. Thomson's theory will seem to be established; and thus not only complete the theory of Lavoisier, but afford an easy solution to some phenomena which have been thought inconsistent with that theory.

Still it must be acknowledged that this is a very obscure subject; the reader would, therefore, do well, before he forms a decisive opinion, to trace the progressive improvement of the theory in the hands of Boyle, Hooke, Mayow, Beccher, Stahl, Scheele, Kirwan, Black, Crawford, Lavoisier, Brugnatelli, and Thomson; with a view to which he may advantageously consult the article *Combustion* in Dr. Gregory's Encyclopædia, and in the Supplement to the Encyclopædia Britannica; Robison's Life of Dr. Black; the Edinburgh Review, No. 5; Nicholson's Journal, N. S. vol. ii.; Nicholson's Chemistry; and Thomson's Chemistry. Tr.

III. ON WATER.

In the exposition which we have hitherto made of the general properties of bodies, we have confined ourselves to the citation of some examples drawn from those which manifest such properties in a more perceptible manner. We shall proceed to consider in succession certain liquids, or certain particular fluids which have a remarkable influence in the phenomena of nature.

The first is water, which we shall consider, first in its ordinary state, which is that of liquidity, then in that of ice, afterwards in that of vapours, which are the extremes between which are found the liquid water.

1. *On Water in the State of Liquidity.*

170. The principal physical properties of liquid water are these; namely, that it is insipid, inodorous, transparent, without colour, and susceptible of moistening the greater part of bodies that are placed in contact with it.

171. All the world knows with what abundance this liquid is diffused in nature, and how diversified are the functions which it exercises. Collected in immense masses in the basins of seas, carried along with a progressive motion over the bed of streams and of rivers, it serves as a vehicle for ships and different kinds of vessels, to establish, by voyages undertaken for commercial and other purposes, a communication between the people of different countries. By its impulsion it becomes the mover of a multitude of machines as useful as ingenious; and if man have at his disposal a power superior still to that which acts in this case, he owes it to the same liquid

converted into vapours. Water is the element in which an infinitude of organised beings live; it supplies drink to man and to the animals that people the earth and the air; it is one of the principal agents of vegetation; it is in its womb that are formed a multitude of minerals, and those precious metallic substances to which human industry seems to have given a new existence by perfecting them for our use.

172. Water was regarded during a long time as a simple substance; and under this relation the ancient philosophers reckoned it one of the four elements that constitute all the bodies in nature; namely, earth, water, air, and fire. This opinion, though distant from truth, had this seducing quality, that it made to concur in the formation of all other beings, those which exist the most generally in the universe; which, occupying as it were so many distinct domains, the one in the celestial spaces, the three others in the region inhabited by man, are nevertheless always holding intercourse one with the other and with the rest of nature; which, finally, seemed the only fixed and unalterable beings in the midst of alternatives which cause an incessant variation in the scene of animals, of plants, and of minerals.

The modern chemistry has substituted for these systems originating in abstract considerations theories founded upon facts; and among the latter, one of the most remarkable is the decomposition into oxygen and hydrogen of this same liquid which had been ranked among the elementary substances. We limit ourselves to the indication of this result, the detail of which does not enter into our plan *(z)*.

173. Rain water is that which approaches nearest to the state of purity. Chaptal has observed that the water

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(z) The inquisitive reader, however, may find it in the article *chemistry*, in the Sup. Ency. Britan., together with the two kinds of proofs that water is actually a compound; those arising from its having been really composed and decomposed. Tr.

which accompanies storms is more mingled than that of a gentle rain, and that this latter becomes more pure in proportion to its duration *. The water which washes the surface of the globe, or flows within it, is always charged with heterogeneous substances. It is known that that of the sea and of many fountains contains more or less abundantly a salt which is drawn from it by evaporation, and which is known under the name of *sea-salt* (muriat of soda, or sal gem). Those are called *mineral-waters* which contain different saline, metallic, or other substances; they are employed successfully in the treatment of various maladies: they borrow from the substances united with them a particular savour, and sometimes a peculiar odour. With respect to river water, it holds in solution various stony matters, and particularly calcareous particles; and that which runs along in the bowels of the earth forms incrustations of the same moleculæ, sometimes in the interior of the canals that receive them, at others about such organised bodies as are immersed in them.

174. It has been attempted to compress water by employing a very great force, but without effect; and this property of being incompressible as to sense is general for all liquids. One of the experiments which have served to shew this, with respect to water, consists in charging that liquid with a column of mercury, by employing a bent tube in form of a syphon, the shortest branch of which is closed at its superior part, and contains water at the same time that the longest branch is occupied by the mercury which presses the surface of the water. The column formed by this latter fluid was not shortened by the smallest perceptible quantity, even when that of the mercury was 227 centimeters or about 7 feet high, in which case it exerted upon the water an effort triple of that of a column of water 33 feet high. There is, notwithstanding, reason to presume that water is really com-

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* Elements of Chemistry, Vol. I.

pressible, but in an inappreciable degree, at least by the efforts which have been hitherto employed to condense it; for the faculty which it possesses of transmitting sounds proves that it is elastic, and this quality necessarily supposes compressibility (a).

On Hygrometry,

175. The observation of various phenomena produced by that which is called *humidity*, has given birth to a new branch of physics bearing the name of *hygrometry*. We shall proceed to exhibit the principles relative to the general theory of these phenomena, and shall then describe the *hygrometer*, or the instrument employed to measure the humidity of the air.

176. All bodies that are susceptible of imbibing water, have a greater or less disposition to unite themselves with that fluid, by the effect of an attraction similar to chemical affinity, joined to the texture of their parts, and to other circumstances.

If we plunge into water several of these bodies, such as wood, a sponge, paper, &c., they will appropriate to themselves a quantity of that liquid, which will vary

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(a) It is rather singular that, excepting the *Abbé Monges*, who made a number of similar experiments to those of Mr. *Canton*, and obtained like results, scarcely any of the continental philosophers should refer to the labours of our ingenious countryman relative to the compressibility of water. Mr. Canton, after having proved that water is really compressible, found by repeated trials that in a temperature of 50° on Fahrenheit's scale, and when the mercury was at its mean height in the barometer, the water expanded one part in 21740; and was as much compressed by the weight of an additional atmosphere; or the compression of water by twice the weight of the atmosphere was one part in 10870 of its whole bulk. He also found that water was more compressible in winter than in summer; but the contrary with respect to spirit of wine, and oil of olives. Hence it would seem that the experiments of which M. Haüy speaks, were not conducted with sufficient accuracy and circumspection. Tr.

with the bodies respectively; and as in proportion as they tend towards the point of saturation their affinity for the water continues to diminish, when those which have most powerfully attracted the water have arrived at the point where their attractive force is found solely equal to that of the body which acted most feebly upon the same liquid, there will be established a species of equilibrium between all those bodies, in such manner that at this term the imbibition will be stopped.

Here then we see that there is a parity between the manner in which bodies absorb caloric, and that in which they imbibe water; that the principal condition which determines the equilibrium is alike in both, and that it depends on the different capacities of the bodies for the fluid which heats them, or for that which moistens them.

If there be brought into contact two wetted or soaked bodies, whose affinities for water are not in equilibrio; that whose affinity is the weakest will yield of its fluid to the other, until the equilibrium is established; and it is in this disposition of a body to moisten another body that touches it, that what is called *humidity* properly consists.

177. Of all bodies, the air is that of which we are most interested to know the different degrees of humidity, and it is also towards the means of procuring this knowledge that philosophers have principally directed their researches; hence the various kinds of instruments that have been contrived to measure the humidity of the air.

178. A multitude of bodies are known in which the humidity, in proportion as it augments or diminishes, occasions diverse degrees of dilatation or of contraction, according as the body is inclined to one or other of these effects, by reason of its organisation, of its texture, or of the disposition of the fibres of which it is the assemblage. For example, water by introducing itself within cords makes the fibres twist and become situated obliquely, produces between those fibres such a separation as causes the cord to thicken or swell, and, by a necessary consequence,

to shorten. The twisted threads of which cloths are fabricated, may be considered as small cords which experience in like manner a contraction by the action of humidity; whence it happens that cloths, especially when wetted for the first time, contract in the two directions of their intersecting threads; paper, on the contrary, which is only an assemblage of filaments very thin, very short, and disposed irregularly in all directions, lengthens in all the dimensions of its surface, in proportion as the water, by insinuating itself between the intervals of those same filaments, acts by placing them farther asunder, proceeding from the middle towards the edges.

179. Different bodies have been employed successively in the construction of thermometers, chosen from among those in which humidity produces the most sensible motions. Philosophers have sought also to measure the humidity of the air by the augmentation of weight undergone by certain substances, such as a tuft of wool, or salt, by absorbing the water contained in the air.

But, besides that these methods were in themselves very imperfect, the bodies employed were subject to alterations which would make them lose their hygrometric quality more or less promptly; they had, therefore, the double inconvenience of being inaccurate, and not being of long service.

180. To deduce from hygrometry real advantages, it must be put in a state of rivalry with thermometry, by presenting a series of exact observations, such as may be comparable in the different hygrometers.

The celebrated Saussure, to whom we are indebted for a very estimable work on hygrometry, has attained the accomplishment of this object by a process of which we shall attempt to give some idea.

The principal piece in this hygrometer is a hair, which Saussure first causes to undergo a preparation, the design of which is to divest it of a kind of oiliness that is natural to it, but that secures it to a certain point, from the action of humidity. This preparation is made at the same time upon a certain number of hairs forming a tuft, the thickness of which need not exceed that of a writing pen, and contained in a fine cloth serving them for a case. The hairs thus enveloped are immersed in a long-necked phial full of water, which holds in solution nearly a hundredth part of its weight of sulphat of soda, making this water boil nearly 30 minutes; the hairs are then passed through two renewals of pure water, while they are boiling; afterwards they are drawn from their wrapper, and separated; then they are suspended to dry in the air; after which there only remains to make choice of those which being the cleanest, softest, most brilliant, and most transparent, deserve to be employed in preference.

It is known that humidity lengthens the hair, and that the process of drying shortens it. To render both these effects more perceptible, Saussure attached one of the two ends of the hair to a fixed point, and the other to the circumference of a little moveable cylinder, that carries at one of its extremities a light index or hand. The hair is bound by a counter weight of 16 centigrammes, or about 3 grains, suspended by a delicate silk, which is rolled in a contrary sense about the same cylinder. In proportion as the hair lengthens or shortens, it causes the cylinder to turn in one or the other direction, and by a necessary consequence, the little index turns likewise, the movements of which are measured on the circumference of a graduated circle, about which the index performs its revolution as in common clocks. In this manner a very small variation in the length of the hair becomes perceptible by the much more considerable motion that it occasions in the extremity of the index; and it will be easily conceived that equal degrees of expansion or of contraction in the hair, answer to equal arcs described by the extremity of the index.

To give to the scale such a basis as may establish a relation between all the hygrometers that are constructed from the same principles, Saussure assumes two fixed terms, one of which is the extreme of humidity, and the other that of siccity: he determines the first by placing the hygrometer under a glass receiver, the whole interior surface of which he had completely moistened with water; the air being saturated by this water acts by its humidity upon the hair to lengthen it. He moistened anew the interior of the receiver as often as it was necessary; and he knew that the term of extreme humidity was attained, when by a longer continuance under the receiver the hair ceased to extend itself.

To obtain the contrary limit of extreme siccity, the same philosopher made use of a hot and well-dried receiver, under which he included the hygrometer with a piece of iron plate likewise heated and covered with a fixed alkali. This salt, by exercising its absorbent faculty upon the remaining humidity in the surrounding air, causes the hair to contract itself until it has attained the ultimate limit of its contraction.

The scale of the instrument is divided into a hundred degrees. The zero indicates the limit of extreme siccity, and the number 100 that of extreme humidity. The inventor was aware of the advantages of the decimal division, and did not hesitate to adopt it.

The effects of moisture and of dryness upon the hair are modified by those of heat, which acts upon it, sometimes in the same sense, and sometimes in a contrary one; so that, if it be supposed, for example, that the air is heated about the hygrometer, on one part, this air whose dissolving faculty with regard to the water will be augmented, (as we shall explain in the sequel), will take away from the hair a portion of the water which it had imbibed, thus tending to shorten the hair; while, on the other part, the heat, by penetrating it, will tend, though much more feebly, to lengthen it; and hence the total effect will be found complicated of two partial and contrary effects, the one hygrometric, the other pyrometric. In observations which require a certain precision, it is therefore necessary to consult the thermometer at the same time with the hygrometer; and on this account the inventor has constructed from observation a table of correction, which will put it in the power of philosophers always to disentangle the principal effect, or the degree of humidity of the air, from the accessory effect produced by the heat.

181. Deluc, who devoted his attention to the same object, has followed a different method. This philosopher employed for the construction of his hygrometers a very thin slip of whalebone, which performs the same office as the hair in the hygrometer of Saussure. He kept this whalebone bent by means of a spring, the action of which he preferred to that of a weight: he determined the degree of extreme humidity by immersing the slip of whalebone entirely under water; and to fix the opposite limit, which is that of extreme siccity, he made use of calcined lime, which he enclosed with the hygrometer under a glass bell. The choice of this substance is founded on this, that the calcination having produced a higher degree of dryness, if it be afterward left to cool so far that it may be placed without inconvenience under the glass bell destined for the experiment, it will be still found, as to sense, in the same state of dryness, since it is very slow in acquiring humidity; and thus all its absorbent faculty will be employed to dry up, by little and little, the air contained under the receiver, and to make the hygrometer itself pass to a state which approaches the nearest possible to extreme siccity *(b)*.

182. The hygrometer has been long neglected in meteorological observations; it is necessary to associate with it the thermometer and the barometer to be in a state to

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(*b*) The essays on this subject by M M. Deluc and Saussure, wear a controversial aspect. Deluc's papers may be seen in the Philosophical Transactions, vols. 63, and 81, and in his "Idees sur la Meteorologie," vol. 1. an. 1786. Saussure's are in his "Essais sur l'Hygrometrie," an. 1783; and "Defence of the Hair Hygrometer," an. 1788. Tr.

unravel the complication of different causes which influence the variations of the atmosphere; and it is only by the aid of a long series of observations, made by the concourse of these various instruments, together with all the indications which are deduced from the state of the heavens, that we can obtain such data as will enable us to prognosticate with great probability the temporary changes, and to arrive at a plausible theory upon this object so interesting, and so naturally calculated to excite our curiosity. We exist in a continual dependance upon the atmosphere, and upon the timely alternatives of serene and rainy days, for the labours of agriculture, for our voyages, for our various enterprizes, and even for our festivities. We shall, therefore, find the useful blended with the agreeable, in an art which would put it in our power to take precautions against what we apprehend, and to enjoy by well-founded anticipation that which excites our hopes.

On Capillary Tubes.

183. The phenomena of capillary tubes are connected, to a certain point, with those of hygrometers, by the respective analogy existing between the producing causes of both. We shall attempt to clear up the species of paradox which they present, in so far as they seem to furnish an exception to the ordinary laws of hydrostatics.

If we plunge into water a tube open at both extremities whose interior diameter has a certain extent, the level will still exist the same within as without the tube; but if the tube is *capillary*, that is to say, if its cavity represents a cylinder thin enough to be compared to a hair, at the moment of immersion the water will shoot forwards within it, and will there remain suspended at an altitude very perceptibly above the level of the exterior water.

We might proceed to conceive the experiment made in one of the cases where the phenomena are the most striking; but these phenomena are subjected to the law of continuity, and make their progress by imperceptible variations, as others do (*c*). In tubes of an ordinary diameter, the upper surface of the interior water forms a little concavity, the borders of which are elevated a little above the level, by applying themselves against the glass. If tubes are employed always more and more narrow, there will soon be found a term where the axis of the column will visibly jut beyond the level; and this effect will be always encreasing, in proportion as the diameter of the tube shall be smaller.

(*c*) The *Law of Continuity* is a term which, though it be frequently employed by the continental philosophers, has as yet been seldom adopted in England: it will not therefore be improper to define it in this place, and to present the reader with what has been thought the best demonstration of its universality. *The law of continuity is that by which variable quantities passing from one magnitude to another, pass through all the intermediate magnitudes, without ever passing over any of them abruptly.* Many philosophers and metaphysicians have asserted the probable conformity of natural operations to this law; but Father Boscovich goes farther, and proves that the law is universal. Thus we see that the distances of two bodies can never be changed without their passing through all the intermediate distances. We see the planets move each with different velocities and directions in the several parts of its orbit; but still observing the law of continuity. In heavy bodies projected the velocity increases and decreases through all the intermediate velocities: and the same happens with regard to electricity and magnetism. No body becomes more or less dense without passing through the intermediate densities. The light of the day increases in the morning and decreases at night, through all the intermediate possible degrees. And thus, if we go through nature we shall, if all things be rightly contemplated, see the law of continuity strictly to take place. We sometimes, it is true, make abrupt transitions in our minds; as when we compare the length of one day with that of another immediately following, and say that the latter is two or three minutes longer or shorter than the former, passing all at once, in the common way of speaking, completely round the globe; but if we consider the several intervening longitudes, we shall find days of all the intermediate lengths. Sometimes also we confound a quick motion with an instantaneous one: thus we are apt to imagine that a ball is thrown abruptly out of a gun when fired; but, in truth, some space of time is required for the gradual inflammation of the powder, the rarefaction of the air, and the communication of motion to the ball. In like man-

184. The law of the phenomena, as it is given by experience, consists in this, that the same fluid is elevated in different homogeneous tubes, to altitudes which are in the inverse ratio of the diameters of those tubes.

185. Observation shews, at the same time, that the heights to which different liquors are elevated in the same tube are not proportional to the densities of those liquors; alcohol, for example, does not rise so high as water.

186. Mercury, on the contrary, is retained below

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set all the other apparent objections to the law may be satisfactorily solved.

But however forcible this argument from induction may be, Boscovich goes still farther, and maintains that a breach of this law, in the proper cases, is metaphysically impossible. This argument he draws from the very nature of continuity. It is essential to continuity that, where one part of the thing *continued* ends and another part begins, the limit be common to both. Thus, when a geometrical line is divided into two, an indivisible point is the common limit of both: thus time is *continued;* and therefore where one hour ends, another immediately begins, and the common limit is an indivisible instant. Now, as all variations in variable quantities are accomplished in time, they all partake of its continuity; and hence none of them can hasten by an abrupt transition from one magnitude to another, without passing through the intermediate magnitudes. As we cannot pass from the sixth hour to the ninth without passing through the seventh, and eighth; because, if we did, there would be a common limit between the sixth hour and the ninth, which is impossible; so likewise you cannot go from the distance 6 to the distance 9 without passing through the distances 7 and 8; because, if you did, in the instant of passage you would be both at the distance 6 and at the distance 9, which is impossible. In like manner, a body that is condensed or rarefied cannot pass from the density 6 to the density 9, or *vice versa,* without passing through the densities 7 and 8; because, in the abrupt passage, there would be two densities, 6 and 9, in the same instant. The body must pass through all the intermediate densities. This it may do quickly or slowly, but still it must evidently pass through them all. The like may be said of all variable quantities; and thence we may conclude that the law of continuity is universal.

The most prominent objections to this law are answered in the able view of *Boscovich's Philosophy,* given in vol. I. *Supplement Encyclopædia Britannica.* Tr.

the level, and its depression is in the inverse ratio of the diameter of the tube. But these effects suppose that the tube was taken in the state it was naturally presented; for we shall shew presently, that by means of certain precautions we may produce a like elevation of the mercury above the level.

187. Finally, if the interior of the tube be coated over with a layer of greasy matter, such as oil or tallow, the same effects will cease to have place, and the fluid will retain its level.

188. The explication of these phenomena has strongly exercised the sagacity of philosophers. Some have attempted to assign a reason, by supposing that the air can only introduce itself into the tube with difficulty and in small quantities, exerting upon the interior column a less pressure than that of the surrounding air upon the exterior liquid; and if it were objected to them that the same effects take place in a vacuum, they would reply that, as a perfect vacuum can never be made, the air which remained under the receiver in all the exterior parts of the tube retains the same ratio with the interior air, the inequality of pressure and the resulting difference of level ought still to subsist: others have had recourse to a subtile fluid to explain the phenomena, and the opinions were divided anew respecting the manner of action of that fluid. According to some, its parts were of a globular form, which would not permit them to arrange themselves exactly in a tube of a small diameter, to exert upon the column which occupied that tube a pressure equal to that which the exterior columns would experience on the part of the same fluid: according to others, the subtile matter would form little vortices, whose moleculæ having a circular motion in the planes that passed through the axis of the tube, and coming to rencounter the interior orifice, would compel the column included in the tube to move upward.

A single consideration will suffice to overthrow all these hypotheses: which is, that the heights to which different liquors rise in the same tube, are not proportional to the densities of those liquors, which should, however, be the case in these hypotheses, since the subtile fluid which would produce the phenomena, in whatever manner it acted, ought most to favour the elevation of the least dense liquids, they being less susceptible of opposing its action.

Thus philosophers agitated themselves uselessly to find in exterior and invisible agents the true cause of the phenomena; while that cause existed even in the tube they had in their hands, and depended upon that species of attraction which has been denoted by the name of *attraction at small distances.*

189. Newton, after having found in universal gravitation the principle of the celestial motions, and of the phenomena where nature acts at large upon masses, sometimes separated by immense intervals (49), had observed also the effects of a certain attraction which only acted near to contact, and from particle to particle. The chemists, who have had continually under their eyes examples of the actions of this force in the composition and decomposition of bodies, have adopted it under the name of *affinity.* The philosophers have been more tardy in tracing it as to its other effects, where the substances solicited by them retain their natural state, a circumstance which takes place with regard to the phenomena of capillary tubes. They chose rather to attribute these effects to the pressure of some effluvia, or to some vortex of subtile matter, which presented itself under the specious appearance of a mechanical cause, but which the phenomena would always contradict in some particular, though the contriver of the theory had the power of adapting it beforehand, and of modifying it at pleasure. This was, as it were, the ultimate refuge of vortices, which,

after having been banished from the celestial regions, sought shelter and support in the nooks of nature, where attraction, reproduced under another form, again disputed the place with them. This attraction was compared with the former; and as it seemed to differ by its manner of acting, by reason of the distances, besides that it was modified according to the diversity of circumstances in which it acted; the philosophers who adopted it were accused of multiplying causes arbitrarily, and of conceiving as many particular attractions as there were presented new facts to explain. But an attentive examination would suffice to render manifest that, even supposing this attraction may be distinguished from universal gravitation, it is not less a force unique in its kind, which extends itself to a numerous class of phenomena, whose diversities depend on those which exist between the bodies on which its action is exerted. Newton remarked that this force once admitted, the whole of nature became simple and of especial accordance with itself; while physical astronomy on one part, and ordinary physics on the other, had each its attraction; and separated between these two forces, the explication of motions, which from afar strike our notice, and of those which require to be pursued near at hand. But probably even this was not saying enough, since by the aid of a plausible hypothesis, of which we have spoken in a preceding part of this treatise (55), we attain a farther simplification of the picture by referring these two attractions to one only.

190. To return now to the phenomena of capillary tubes, it is not difficult to conceive at first sight, by obvious reasoning, how a liquid becomes elevated above its level, though in tubes of a greater diameter, it remains, as to sense, at the same height as the surrounding liquid; respecting which it is necessary to

observe, that the attraction of the tube, which is only perceptible near the state of contact, acts only upon the almost infinitely thin annulus of liquid which adheres, under the form of a hollow cylinder, to its interior surface. The moleculæ of this stratum then act by their proper attraction upon those of the second, and thus from one to another unto the moleculæ which correspond with the axis of the column.

But, the narrower the tube the more its curvature returns upon itself; whence it follows that the moleculæ exert upon the liquid more concentrated actions; insomuch that if we suppose a particle of this liquid placed at the same distance from an attracting point taken upon the curve surfaces of two different tubes, the little arc of which this point will occupy the middle in the narrowest tube, being more inflected towards the same particle, will act upon it by attractions nearer to contact: whence it appears that there may be a term of contraction in breadth, where the attraction of the tube becomes capable of holding the liquid suspended to a sensible height: by a necessary consequence the mutual attractions of the concentric strata which proceed from the surface to the axis, would result from a higher degree of force in a narrower tube; they would diminish more slowly; and lastly, they would have to go over a less number of decreasing degrees, between the surface and the axis: whence it results that their total effect will be so much more considerable.

191. Many philosophers who have ascribed to attraction the effects of capillary tubes, have believed they were able to demonstrate rigorously the inverse ratio between the height and the diameter of the column when different tubes are plunged in the same liquid. Jurin, who has made a series of interesting experiments on the phenomena under consideration

(*d*), attributes the suspension of the liquid to the action of the annulus of glass situated immediately above the column of the liquid. Other philosophers think that the same effect arises, on the contrary, from the annulus which terminates the tube at bottom, supposing that the orifice of this tube were contiguous to the surface of the water. Now, by combining the force of the attracting annulus with the quantity of the liquid which is elevated in the tube, we might attain a result which would accord sufficiently well with observation. For example, in the second hypothesis, the attractions of the tubes were as the circumferences of those tubes, or, which comes to the same, as their diameters; but they were at the same time as the weights of the cylinders of liquid suspended (above the level) in the tubes, that is to say, as the squares of the diameters multiplied into the altitudes, which gives the inverse ratio between the diameter and the height*.

192. The truth is that when the elevation of the same liquid in two different tubes is compared, the attraction of each surface is the result of all the particular attractions exercised by the different particles of the glass upon all those of the liquids which are at distances sufficiently small to suffer the effect of those attractions. This is the remark of Clairault, in his excellent work on the figure of the earth (pa. 105, et. seq.), where that illustrious mathematician treats the question of capillary tubes, according to the general laws of hydrostatics, by causing to enter as elements, into the

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(*d*) Dr. Jurin's account of his experiments, and his enquiry into the cause of capillary attraction, were published in No. 355 of the Philosophical Transactions. See also New Abridgement of Phil. Trans. vol. VI. pa. 330. Tr.

* Let D, d, be the diameters, and H, h, the heights. We have, by the hypothesis, $D : d :: D^2 \times H : d^2 \times h$; whence we deduce $d D^2 H = D d^2 h$, or $DH = dh$; that is, $H : h :: d : D$.

expression of the force which holds the fluid suspended, the different actions that concur in the production of the effect.

We shall attempt to give an idea of the method by which he was enabled to express generally this concourse of combined actions.

Let A B C D E F G H (fig. 21. pl. III.) be a section of a capillary tube, made by a plane passing through the axis, M N P the upper surface of the water in which it is plunged, I *i* the height to which that liquid is elevated in the tube, Y I Z the little concavity which forms its upper surface, by the effect of the attraction: let us conceive, in the place of the axis of the tube, an indefinitely thin column I K, the inferior extremity of which K is out of the sphere of sensible activity of the tube, and assume, in like manner, in the surrounding water, a column M L also situated vertically, at such a distance from the tube that the latter cannot act upon any of its particles: finally, let us imagine that there is a little horizontal canal L K establishing a communication between the two vertical columns. The object of the problem is to enquire whether, by combining the different forces that solicit these two columns, there can be obtained any possible case of equilibrium between the one and the other.

Now, the exterior column M L is solicited by two different forces: one of these is the force of gravity which acts through the whole extent of the column; the other is the reciprocal attraction of the moleculæ which acts the same in all the points of the column, but which only exhibit their effect towards the extremity M. To represent the element of this action, suppose a particle *e*, situated in the column at a less distance from the surface or level of the water than that where the attraction of the liquid generally terminates, and conceive another plane *m n* below, parallel to the level, and at the same distance from the particle *e*: it is manifest that this particle will be equally attracted upwards and downwards by the water comprised between the two planes M N, *m n*, since there is an equality between the quantities of the liquid situated on both sides. But the water which is below the inferior plane *m n*, whose action is not balanced by any other, will draw the particle towards it, and this effect will have place as far as the distance where the attraction becomes a nullity.

Now, if we would consider the forces that solicit the other column I K taken in the place of the tube's axis, we have, first, the force of gravity, which acts also through all the extent of this column: with regard to the other forces, we must distinguish between those which relate to the superior part of the column, and those which regard the part in the vicinity of the inferior extremity of the tube.

But towards the upper part there are two forces which act; namely, the attraction of the tube upon the moleculæ of the water, and the reciprocal attraction of those moleculæ. Now the tube being supposed of an indefinite length by its part elevated above the water, and its inferior extremity C D G H being at a distance from the aqueous moleculæ near to the point I much greater than that to which the attraction of the glass can extend, every particle situated at the same point is as much drawn upwards as downwards by the force of the tube; and hence we may drop the consideration of that force. In order to estimate the reciprocal attraction of the aqueous particles, let a horizontal plane V X be drawn so as to touch the little concavity formed by the upper surface of the water in the tube: this done, a particle *p*, situated infinitely near to I, is attracted by all the moleculæ that are situated above V X at a suitable distance for the taking place of that attraction, and at the same time by all the moleculæ situated below V X, which are in the same relative case; but since the liquid forms a vacuity at its upper part, there will be on that side fewer attracting moleculæ in a given space between two planes parallel to V X than in the lower part; whence it follows, that the real force soliciting the particles situated towards the extremity I is exerted downwards.

It remains to consider what happens towards the inferior part O of the tube. Now, to estimate the value of the forces which act at that place, we must suppose that the tube has a prolongation down to the bottom of the vessel, formed of matter equal in density to the water; for this puts it in our power to take account of the action exerted by the surface of the water that forms a continuation of the interior surface of the tube. This granted, we may consider the actions experienced by two attracted moleculæ R, Q, one of which is situated within the tube a little above its extremity, and the other out of the tube at the same distance below that extremity. It is, at first sight, evident that the actions exerted upon the moleculæ situated in that place, by the water comprised between the sides B D, E G, of the tube, and between the fictious prolongation of the same tube, mutually destroy each other; since the water extends itself about those moleculæ much beyond the radius of its sphere of activity. We have only therefore to consider the action of the tube, and of its prolongation, upon each of the moleculæ R, Q. But, the first is drawn upwards by the superior particles of the tube, from which that particle is more distant than from the inferior annulus of the same tube; which we may conceive by applying here that which has been said with respect to the action of the liquid, that is to say, by supposing two planes *c d g h*, C D G H, which intercept on both sides the parts that are in equilibrio: now, the same particle is attracted downwards, though more feebly, by the prolongation which has been supposed of the tube; and it is the difference between the two actions which produces the real effect. On the other part, the particle Q, situated below the extremity of the tube, is drawn upwards by the tube, and with the same force as the first particle, since by the hypothesis it is as far distant from the points D, G, situated at the beginning of the tube, as the particle R is from the points *d*, *g*, where, with respect to it, the real attraction of the tube commences. But it is attracted in like manner downwards by the prolongation of the tube; and the difference between these two actions is here again the same. Thus, by doubling it, we have the sum of the actions which are exerted towards the base of the tube; these actions combined with those that relate to the superior part of the tube, and to that of gravitation which solicits the entire column, give the total expression which should be compared with that of the forces that act upon the exterior column.

Now, though these expressions only represent in a general manner the intensities of the attractions and the functions of the distance, which are unknown; it is nevertheless evident that there are an infinitude of possible laws of attraction, each of which will give a sensible quantity for the elevation above the level, when the diameter of the tube is very small; and, on the contrary, a quantity next to nothing for the case where the diameter is rather considerable; and among the same laws of attraction, we may select one which gives the inverse ratio between the diameter of the tube and the altitude of the liquid (computing from the level) conformably to experience.

The expression obtained by Clairault leads to this singular consequence, that even when the attraction of the capillary tube had an intensity less than that of the water, provided this intensity were not half as small, the water would not cease to be raised.

193. With regard to the depression of the mercury below its level when admitted into a capillary tube, it has been supposed that it is occasioned by the circumstance of the moleculæ of that liquid metal being attracted much more strongly towards one another than they were attracted by the tube; for, on this hypothesis, we ought in fact to have effects contrary to those which take place with respect to ordinary liquids.

But the experiments made at Metz by Professor Casbois prove that when the tube and the mercury are both perfectly dry, the metal rises above its level in the same manner as aqueous liquids. This philosopher luted together two glass tubes, one of which, that had a sensible diameter, and a length of about three inches, was closed at one of its extremities; the other extremity, which was open, communicated with a capillary tube of about $\frac{1}{4}$ of a line in diameter, and 36 inches long. The aggregate of the two tubes was curved at the place of their junction, as in the syphon, and the capillary tube was turned towards its extremity, which carried a reservoir in form of an open ball, as in many common barometers. The whole was filled with mercury, which had been boiled several times to free it, as far as possible, from its humidity. Then, having so disposed the tubes that the capillary branch was situated vertically, and that the part which carried the reservoir was turned towards the bottom, the mercury was seen to descend nearly to 28 French inches in the capillary branch. By means of the blowpipe and enameller's lamp the portion which exceeded 30 French inches was detached from that branch; and the extremity of such portion, as well as that of the branch from which it had been separated, was sealed hermetically by the same operation. Thus there was, on one part, a capillary barometer, and on the other a syphon composed of a thick branch and of a capillary one, both sealed at their extremity: and as a part of the mercury remained suspended in the thick branch while the rest descended in the capillary barometer to the altitude of 28 French inches, afterwards, when this syphon was situated in such manner that its convexity was directed towards the earth, the mercury was elevated at the same time in both branches.

Now, on comparing the capillary barometer with other barometers, it was remarked that the mercury in it was retained two or three lines the highest; and with regard to the syphon, the height of the column of mercury which occupied the capillary branch exceeded by the same quantity that of the corresponding column*.

It appears from these experiments that the depression of the mercury below the level in the ordinary case, is the effect of a little moist film which attaches itself to the interior surface of the tube, and whose interposition suffices to weaken perceptibly the attractive virtue of the glass with regard to the mercury, and to render preponderant the mutual affinity of the particles of that metal. When that humidity is suppressed, the mercury (so far as relates to capillary attractions) returns into the analogy of other liquors. Even they have likewise their case of exception, which is that where the interior of the tube is done over with a coat of oily matter, which prevents the liquid from attaining a sufficiently great proximity with the glass, and having, of itself, only a very small action upon the liquid, destroys the influence of the tube in disturbing the effect of the ordinary laws of hydrostatics.

194. By carrying to the extreme the dryness of the mercury, and that of the tube which contains it, barometers may be procured in which the column of mercury will be terminated at top by a plane face. La-

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* Dictionnaire Encyclopédique, supplement, tom. IV. pa. 981.

place and Lavoisier have constructed such barometers, and have even been able to render the upper surface of the mercury concave; but they did not regard these instruments as more perfect than the usual barometers; because though, on one hand, the dryness gave an advantage to the pressure of the atmosphere, by suppressing the contrary action of the little vapour which is commonly formed above the mercury, on the other hand, the excess of adherence which this liquid contracted with the glass diminished the mobility of the column; so that it was necessary to shake the barometer to cause the effect of such adherence to disappear; and thus it was doing nothing else than substituting a constraint of a new species for that from which the instrument had been freed.

We have said (185) that the heights to which different liquors are elevated in the same tube do not conform to the ratio of the densities; and it is easy to conceive the reason of this, at least generally, when the phenomenon is attributed to attraction, since that force varies according to the form and the disposition of the moleculæ, to the figure of the pores, and other circumstances which may determine a greater intensity of attraction, relatively to liquids of a less specific gravity.

195. It has been attempted to compare the heights to which different fluids were elevated in the same tube with the diameter of that tube. The results given as to this object by different philosophers vary sensibly from one another; which probably arises from the different compositions of the glass employed in the experiments: yet they have this in common, that the heights of the columns above the level are not proportional to the densities. In the experiments made by Muschenbroek with a glass tube composed of lead and flint, having a length of 7 inches Rhinland

measure*, and an interior diameter of $\frac{1}{50}$ of an inch, water rose to $13\frac{1}{2}$ lines above its level, red-wine to $8\frac{1}{2}$ lines, and alcohol to 6 lines.

Newton has cited an experiment made by means of two plates of glass placed parallel to each other, at the distance of about $\frac{1}{100}$ of an inch, London measure, between which the water rose to an inch above its level in the reservoir.

196. The two plates of glass may be so placed as to form between them a very acute angle: then if we plunge them in water in such a manner that the line of junction be perpendicular to the surface of the liquid, it will be seen to rise suddenly between the two plates, and form a curve which will turn its convexity towards the line of junction, and will pass through the extremities of the different heights to which the liquid ought to be elevated, in proportion as the interval between the two glass plates diminishes. Now, it is easy to conceive that this curve ought to be a hyperbola (*e*). Let $a\,a'\,x'\,x$ (fig. 22) be one of the two surfaces contiguous to the interior faces of the glass plates, $a\,x$ being the line of junction of that same surface with the horizontal surface of the water in which the plates are partly immersed, and $b'\,x'$ the curve formed by the most elevated points of the water comprised be-

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* The Rhinland foot is equal to $11\frac{1}{2}$ inches of the Paris standard foot, and the English foot about 11 inches 3 lines of the same. AUTHOR.

Indeed the English, Rhinland, and Paris feet are respectively as the numbers 1000, 1023, and 1065. TR.

(*e*) Dr. Brook Taylor was the first who *observed* that the upper part of water rising by means of capillary attraction, between two planes inclined in a small angle ($2\frac{1}{2}$° in his experiment), formed a hyperbolic curve. The perpendicular asymptote was, he says, exactly determined by the edge of the glass; but the horizontal one he could not so well discover. Neither Dr. Taylor nor Mr. Hauksbee, who observed the same thing, attempted to *demonstrate* that the figure was actually a hyperbola. See Phil. Trans. No. 336. A. D. 1712, or New Abridgment. vol. v. pa. 706. Demonstrations, however, have found their way into all our late elementary books on Hydrostatics. TR.

tween those plates. We may consider this water as an assemblage of an infinity of little cylinders, whose altitudes are the perpendiculars $x x'$, $t t'$, $r r'$, &c. drawn from the line $a x$ to meet the curve. Let $z a x$, (fig. 23.) be the inferior surface of the water included between the glass planes, in which case the line $a x$ will be the same as in fig. 22. If we draw $x z$, $t u$, $r s$, &c., (fig. 23) perpendicular to $a x$, in such manner that the distances $x t$, $t r$, $r o$, &c., are equal to those in fig. 22. these perpendiculars may be considered as the diameters of the bases of the little cylinders whose altitudes are the lines $x x'$, $t t'$, $r r'$, &c. But, from the law to which the phenomenon is subjected, the heights $x x'$, $t t'$, $r r'$, &c., are in the inverse ratio of the diameters $x z$, $t u$, $r s$, &c. (fig. 23) of the bases; while those diameters are respectively as their distances $a x$, $a t$, $a r$, &c., from the point a: therefore the lines $x x'$, $t t'$, $r r'$, &c., (fig. 22.) are also in the inverse ratio of the lines $a x$, $a t$, $a r$, &c. Whence it follows that the curve $b' x'$ is a hyperbola whose asymptotes are the lines $a x$, $a a'$; so that the lines $x x'$, $t t'$, $r r'$, &c., are the ordinates to the asymptote $a x$, and the lines $a x$, $a t$, $a r$, &c., the abscissas. This is a consequence of the inverse ratio of which we have before spoken: and the experiment is obviously interesting in so far as it generalises its object, and presents a geometrical expression of the phenomenon traced even by the liquid that produces it (*f*).

197. We may represent the effects of capillary tubes by another experiment very easy to perform. It consists in inclining one of those tubes, and letting fall upon its surface a drop of liquid; then, re-adjusting the tube at the

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(*f*) The process of the reasoning would have been just the same, and it would have been more satisfactory because more consistent with fact, if the liquid elevated between the glass planes had been supposed constituted, not of a series of cylinders, but of an indefinite number of prismatic columns whose bases are similar trapezoids gradually augmenting from a towards x. Tr.

moment when that drop, carried on by its weight, has arrived at the inferior orifice; it will be seen to run through that orifice into the interior of the tube.

This experiment, which presents the phenomenon disengaged as much as possible from the laws of Hydrostatics, which are always combined more or less with affinity in the case where it obtains, may serve as a transition to arrive at the explication of a multitude of analogous effects that are continually occurring before our eyes. Such are those that are presented by a piece of a branch of a tree having one of its extremities immersed in water; a piece of sugar which is immersed, in like manner, by a point in coffee liquor, and which in an instant is found moistened up to the top; a heap of sand or of ashes, whose foot is in water, which mounts by little and little till it reaches the summit; the cotton wick, that draws the oil upwards in a lamp; and thus of an infinitude of bodies which Muschenbroek called *the magnets of fluids*, a very improper denomination if that philosopher wished to have it interpreted rigorously. All the different hygrometric substances may here be ranged upon the same line, which commences with capillary tubes (*g*.)

(*g*) Notwithstanding the attention that M. Haüy has paid to the subject of capillary tubes, and the advantages he has derived from Clairaut's investigations, the theory he has exhibited is still imperfect and unsatisfactory. The celebrated Laplace has lately re-examined the difficult points of this theory: and although the result of his enquiries seems to be defective in so far as he has neglected the force of repulsion, which in many cases exactly balances that of cohesion; yet as his manner of treating this curious subject is far preferable to any other that has yet been published, it is judged proper to present in this place some account of it.

M. *Clairaut*, as appears from our author's statement, supposed that the action of the capillary tube is sensible upon the infinitely narrow column of the fluid which passes through the axis of the tube. M. Laplace, on the contrary, thinks with Hauksbee, and many other philosophers, that *the capillary action, like the refractive force and all the chemical affinities, is only sensible at imperceptible distances.* Clairaut's theory leaves us still in need of a complete explication of the chief phenomenon, viz. that *the ele-*

198. The dendritæ, or herborizations which adorn the surface of certain calcareous or argillaceous stones, are

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vation of the fluid above its level in tubes of the same matter, is in the inverse ratio of their diameters: but this desideratum is supplied by the researches of Laplace. This illustrious philosopher has determined by the formulæ in his Treatise on Celestial Mechanics, the action of a fluid mass terminated by a spheric surface, whether concave or convex upon a fluid column contained in an infinitely narrow canal coinciding with the axis of that surface. By this action he means the pressure which the fluid contained in the canal will exert in virtue of the attraction of the entire mass, upon a plane base situated in the interior of the canal, perpendicularly to its sides at any sensible distance whatever from the upper surface, this base being assumed for the unit. He shews that this action is smaller when the surface is concave than if it were plane, and greater when the surface is convex. His analytical expression is composed of two terms, the first of which, much greater than the second, expresses the action of the mass terminated by a plane surface; and he thinks that on this term depends the phenomenon of the adherence of the bodies to one another, and of the suspension of the mercury in a barometer tube at an altitude two or three times greater than that which is due to the pressure of the atmosphere. The second term expresses the part of the action due to the sphericity of the surface; and it is positive or negative according as the upper surface is convex or concave.

M. Laplace shews that in both cases this term is inversely as the radius of the spherical surface; hence he deduces this general theorem, that in all the laws where the attraction is only sensible at insensible distances, the action of a body terminated by a curve surface upon an interior canal infinitely narrow and perpendicular to that surface in any point whatever, is *equal to the half sum of the actions upon the same canal, of two spheres which have for radii the greatest and the least radii of curvature of the surface at such point.*

The application of these results gives the true cause of the ascension or depression of fluids in capillary tubes in the inverse ratio of the diameters. If by the axis of a tube of glass we conceive an infinitely narrow canal, which turns up a little below the tube till it comes to the plane and horizontal surface of the water of a vessel in which the lower extremity of the tube is immersed, the action of the water of the tube upon this canal will be less, by reason of the concavity of its surface, than the action of the water in the vessel upon the same canal; the fluid must therefore *rise* in the tube to compensate for this difference, and as this is, by what has preceded, in the inverse ratio of the diameter of the tube, the elevation of the fluid above its level must conform to the same ratio.

If the fluid be mercury, its surface in the interior of a glass capillary tube is *convex*; its action upon the canal is therefore stronger than that of owing to a similar cause. Among these stones, some are full of fissures in which a fluid charged with ferruginous or other particles has been introduced, and has left little metallic deposits; and as the fissures form a species of ramification, which with sufficient frequency communicate to one principal fissure, the artist takes care to cut the stone in the proper direction, so that all these ramifications are developed upon the same plane, and resemble a little tree, the principal fissure representing the trunk or stem. There are other stones composed of parallel layers like leaves of a book, between which a similar fluid has penetrated, and distributed itself by veins, thus forming dendritæ constituted of metallic globules, ranged in rows one by another. In this case we have only to sepa-

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the mercury in the vessel, and the fluid must *sink* in the tube in proportion to that difference, and consequently in the inverse ratio of the diameter of the tube.

Thus the attraction of capillary tubes has no other influence on the elevation or depression of the fluids which they contain, than in determining the inclination of the first planes constituting that part of the upper surface of the interior fluid which is extremely near the sides of the tube; an inclination on which depends the concavity or convexity of that surface and the magnitude of its radius. If, by the effect of the friction of the fluid against the sides of the tube, the curvature becomes either augmented or diminished, the capillary effect will be augmented or diminished in the same proportion.

Laplace considers likewise the suspension of fluids between parallel planes extremely near to each other, and finds by his analysis that a fluid must rise or fall according as the upper cylindric surface is concave or convex, the elevation or depression conforming to the inverse ratio of the mutual distance of the planes; and, for that the elevation or depression is equal to that which obtains in a cylindric tube of which this distance is the interior radius. This result is confirmed by some experiments made by M. Haüy, at Laplace's request; and is indeed conformable to the experiments stated by Newton in his Optics. See Quest. 31. pa. 366 of the English edition.

The capillary phenomena of planes inclined to each other and of conical tubes, are so many corollaries of M. Laplace's analysis: he gives a familiar account of these particulars in Delametherie's *Journal de Physique*, tom. 62, whence we have extracted the above; but the complete explication of his theory may be seen in *Supplement au dixieme Livre du Traité de Mecanique Celeste, sur L'Action Capillaire.* TR.

rate the laminæ one from another to have a little picture which is entirely the work of nature.

199. It is likewise to actions of the same kind as those that produce the phenomena of capillary tubes, that we ought to attribute the motions by the aid of which two small bodies floating upon a fluid, at a little distance from one another, approach till they are in contact, or fly from one another, according to circumstances. These bodies being among those which are in a state of solidity, cannot exert one upon another any sensible attraction or repulsion; so that what occurs in the motions now under consideration is solely due to the action of the particles of the liquid in contact with the same bodies.

200. If neither of the two bodies is susceptible of being moistened by the liquid; if, for example, they are two globules of wax which float upon the water, and that the distance which separates them is sufficiently small, they will be seen to approach and join one another. To learn in some measure the reason of this it may be observed that, in this case, the surface *b d* (fig. 24. Pl. IV.) of the liquid commences its inflection at a point *d* or *g* situated at a certain distance from that where the globule *a* is immersed; so that it forms a curve in that place whose convexity is turned upward. The same thing obtains with respect to the globule *c* which floats upon the same liquid. So long as the two globules are at a respective distance sufficiently great for an intermediate part of the surface, such as *d b*, to retain its level, the lateral pressure which this liquid exerts on different parts of each globule being equal, the equilibrium will subsist; but if it be supposed that the distance between the two globules is continually diminished, there will be a term where the two curves will tend to intersect one another; the part of the liquid between the two globules will then experience a depression which will disturb the equilibrium, and the lateral pressure which acts on the opposite side becoming preponderant, will push the two globes one towards the other.

201. If one of the two globules, as *a* (fig. 25.), is susceptible of being wetted, and the other globule *b* is not; for example, if the first be cork, the other wax, the liquid will rise about the globule *a*, while on the contrary it will form a cavity about the globule *b*; in such manner that if one be made to advance towards the other until they are at a small distance, the pressure which acts laterally upon *b* on the side of *d*, being stronger than that which has place on the opposite side *g*, because of the elevation of the liquid between *d* and the globule *a*, the other globule *b* will be forced to recoil as if it were repelled by the globule *a*.

This experiment may be varied by placing a globule of wax upon the water, and then plunging in that water at some millimetres from the globule the extremity of a body susceptible of receiving moisture, such as a little stick of wood, having a diameter equal to that of the globule. The latter will retire from the stick; and if we reiterate the immersions always at the same distance, we may direct at pleasure the motion of the globule, by an action which will appear to exert itself at a distance upon that little body.

202. Lastly, if the two globules are both susceptible of taking moisture, they will be borne the one toward the other, and finish by being united. In this case the interval between the two globules may be considered as a capillary tube, in which the water is raised to a greater height than in the parts opposite to those by which the globules face one another. Now, if to assist our conceptions we imagine in the place of the globules two glass plates immersed in the water at one of their extremities, and situated respectively parallel at a small distance; among the different actions which are combined in this case, there is one which depends on the circumstance that the interior surface of each plate is drawn in the lateral sense by the film of water in contact with it; this film in its turn is in like manner attracted by that which is contiguous to it, and thus throughout, so that the plates are

solicited one towards the other by the intervention of the aqueous vertical laminæ which separate them; and the result shews that this action prevails over the others which tend to produce an equilibrium. In proportion as the distance between the plates diminishes the water rises to a greater height, and the force that acts to draw the plates nearer augments at the same time with the surface of contact between the liquid and the glass. We have the limit of the effect which we are considering here when we so press the two glass plates one against the other, that their immediate contact is only prevented by a film of water almost infinitely thin which remains between them. In this case they contract one for the other a force of adhesion, which is due to the attraction exerted upon them by the moleculæ of the intervening aqueous lamina.

203. There may be substituted for the globules two thin needles, which may be gently placed upon the water, where they will float, by the effect of the little stratum of air that adheres to their surface; as that obtains generally for all bodies. The volume of this air being comparable to that of the needle, makes the latter increase in a greater ratio than that of the augmentation of weight; so that the whole is specifically lighter than a like volume of water. If one of the needles be caused to advance towards the other in an oblique direction, until the two extremities touch, they will so continue to incline one towards the other, that the angle which they formed will, at the moment of contact, diminish by little and little, and terminate by the mutual adherence of the needles through their whole length. If, when they meet, the extremity of the one has touched a point situated, for example, at the middle of the length of the other, the point of contact will remain fixed until the two needles adhere together, each projecting beyond the other the half of its length; and immediately they will glide the one along the other until they become even at their extremities.

All these different phenomena which many philosophers have attributed to the reciprocal actions of the bodies which exhibit them depend, therefore, solely on the attraction exerted by the particles of the water, either upon one another, or with respect to the bodies themselves; and this liquid is here the true mover disguised under the appearance of a simple vehicle * (*h*).

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* See the Treatise on the Motion of Water, by Mariotte, Paris 1700, pa. 118, et seq.; and a Memoir of the celebrated Monge, inserted among those of the Academy of Sciences, A. D. 1787, pa. 506, et seq. Mariotte's Treatise has been translated into the English language.

(*h*) The reason assigned by M. Haüy and some other philosophers for the suspension of needles, &c. upon the surface of water, namely that a little atmosphere of air attached to the body renders the whole specifically lighter than water, does not carry with it much probability: at least it is an assigned cause that itself requires a cause, and only removes the difficulty a single step; for it may be asked, how is this small portion so separated from that which surrounds it as to attach itself to the needle, or other minute body, and form but one compound gravitating substance? We should rather say that though a needle, for example, is specifically heavier than the water, the difference in gravitating tendency is not sufficient to overcome the adhesive force with which the particles of water hang together when the needle is applied to the surface horizontally, yet it will generally overcome this adhesion when it is applied vertically to its surface: and this we infer upon the same principle that a countryman when he finds ice will not sustain his weight if he stands upright, lays himself prostrate upon it and crawls along without apprehension of danger.

As this is an interesting topic respecting which the prevailing theories do not seem very satisfactory, it seems proper to give in this place some extracts from a paper by Count Rumford, read at the public sitting of the French National Institute, July 6th, 1806.

The Count, suspecting that the presence of the air attached to the surfaces of the small ponderous bodies which float upon water (which is generally looked upon as the immediate cause of their suspension) was not indispensably necessary to the success of this experiment, made the following investigations.

Having half filled with water a small wine-glass, an inch and a half in diameter at the top, he poured upon the water a layer of vitriolic ether, a quarter of an inch in thickness; and when the whole was perfectly tranquil, he took up with a pair of tweezers a very small needle, which he introduced into the ether, holding it in a horizontal position, and, bringing it gently to the distance of about a line above the surface of the water, he

In the exposition which we have presented of these phenomena, we have only given with regard to the

let it drop. The needle descended to the surface of the water, where it remained floating.

Having poured a large drop of mercury upon a porcelain plate, he crushed it, and formed of it a greater number of small globules. In order to take up and remove one of these small globules, he had a small wire instrument made in form of a hoe. By means of this he took up a small globule of mercury, about a fifth of a line in diameter, and carefully removing it, he conveyed it to the distance of about half a line from the surface of the water upon which the ether rested, then inclining the edge of the small instrument a little forward, he let the globule of mercury fall gently upon the surface of the water, where having descended it remained floating. When holding his eye lower than the surface of the water he viewed the globule from below upwards through the glass, it appeared as if suspended in a kind of sack, a little below the level of the surface of the water.

Having placed a second globule of mercury upon the surface of the water, it immediately moved towards the first, and approaching it with an accelerated motion, it precipitated itself into the same sack, which then became longer; but the two globules did not intermingle with each other.

Having placed a third globule upon the surface of the water, it joined itself to the two others; but the weight of these three globules united being too great to be supported by the kind of pellicle which had formed at the surface of the water, the sack was broken, and the globules descended through the water to the bottom of the glass.

When the experiment was made with a somewhat larger globule of mercury, for example, with one of a fourth or a third of a line in diameter, it always broke the pellicle of the water, and descended through this liquid to the bottom of the glass; but when the viscosity of the water was increased, by dissolving a little gum-arabic in it, still larger globules of mercury were supported upon the surface of the liquid.

The preceding experiments were repeated with a layer of essential oil of turpentine, and afterwards with a layer of olive oil, placed upon the water, instead of the layer of ether; and the results were similar in every respect.

On examining with a good magnifying glass the small bodies supported upon the surface of the water, it was impossible to doubt the existence of the pellicle in question, especially when it was touched with the point of a needle; for when that was done the small bodies resting upon this pellicle were seen thrown all at the same time into a tremulous motion.

If the moleculæ of water adhere strongly to each other, a necessary consequence of this adhesion must be, in the Count's opinion, the formation of a kind of pellicle upon the surface of this liquid, and even *upon all its* forces on which they depend the evidences which are furnished as of themselves, when attention is paid to the

surfaces, whatever otherwise may be the mobility of these moleculæ, or rather of the small liquid masses composed of a great number of these moleculæ, when they are at a distance from the surface, and enjoy a free fluidity.

When a small solid body placed upon the surface of the water becomes wet, it is immediately *below the pellicle of this liquid,* and this pellicle can no longer prevent its descent; and now the viscosity of the liquid begins to manifest itself in a quite different manner; but in a manner infinitely less sensible than when it acts upon the confines of the liquid: It is, however, not yet time to discuss this part of our subject.

With a view to render evident to the senses the resistance which the pellicle of the lower surface of a layer of water opposes to a solid body traversing this layer, and falling freely from the top to the bottom, he made the following experiment. Having filled a small glass with a foot about half full of very pure and clean mercury, he poured upon this mercury a layer of water three lines in thickness, and upon the water a layer of ether two lines thick. When the whole was tranquil, he took, with the small instrument above described, a globule of mercury, about a third of a line in diameter, and let it fall through the layer of ether. This globule, being too heavy to be supported by the pellicle upon the upper surface of the layer of water, broke it, and descended through this liquid; but when it had arrived at the lower surface it was stopped, and remained there, retaining its spherical form. The Count moved this globule with the end of a feather; he even compressed it; but it still retained its form, without mixing with the mass of mercury, upon which it seemed to rest. It was undoubtedly the pellicle of the inferior surface of the layer of water which prevented this contact; and as this pellicle was supported by the mercury upon which it rested, he was not at all surprised to find that it could bear, without breaking, a much larger globule of mercury than the pellicle of the upper surface of the water had been able to support.

In order to convince himself that the viscosity of the water was the cause of the suspension of the globule of mercury at the bottom of the water, he repeated this experiment, and varied it by substituting water that contained a certain quantity of gum-arabic in solution instead of the pure water, and he actually found that globules much larger still were supported when the viscosity of the water was augmented by this means.

The adhesion of the moleculæ of water with each other is the cause of the preservation of this liquid in masses. It covers its surface with a very strong pellicle, which defends and prevents it from being dispersed by the winds. Without this adhesion, water would be more volatile than ether, more fugitive than dust.

The viscosity which results from the mutual adhesion of the particles different figures which, according to circumstances, are assumed by the liquid on which the bodies float. But the precise determination of the results given by experience would be the object of a very complicated analytical calculus, and would require a hand whose ability was commensurate to the delicacy of the problem.

2. *Water in the State of Ice.*

The congelation of water, which we shall now proceed to contemplate, is, of all the phenomena produced by the transition from liquidity to solidity, the most general, and that which most deserves our notice. We shall join to the developement of the circumstances which determine and accompany it, some details relative to the same phenomenon offered by other bodies, whence there will result some analogies calculated to fix the attention.

204. When a mass of water, exposed in a vessel of a suitable temperature, passes to the solid state; if the congelation is not too rapid, there will first be seen formed at the surface little triangular spires or needles, of which one of the faces is on a level with the surface of the water. As these little needles are multiplied

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of water, renders this liquid capable of holding in solution all kinds of bodies, even the lightest and the heaviest bodies, provided always that they be reduced to very minute particles. Count Rumford has found by a calculation, founded upon facts, which have appeared to him decisive, that a solid globule of pure gold, of a diameter of a three hundred-thousandth part of an inch, would be suspended in water by the effect of its viscosity, even though this small body were completely wetted and submersed in a tranquil mass of this liquid.

This viscosity, or want of perfect fluidity in water, which causes it to hold suspended all sorts of substances in solution, renders it eminently adapted to be *the vehicle of the nourishment of plants and animals*; and we accordingly see that it is water which exclusively performs this office. Rep. of Arts, &c. No. 51. Tr.

they will be inserted one upon another, and the interstices which they leave will be found successively occupied by new needles, the whole assemblage at length forming as it were one and the same body.

In the case of a very slow congelation the needles will have a kind of indentations, and imitate in their arrangement the initial crystallisations that the refrigeration which succeeds to fusion causes to appear upon the surface of most metals, and which have been compared to the small branches of fern. Ramified congelations are also observed at the surface of glass windows during the time of a frost.

A remarkable circumstance of these arrangements is the tendency of the spires to unite with one another under angles of 120 or of 60 degrees. This disposition is exhibited with a particular character of symmetry in snow, which falls with sufficient frequency in form of little stars with six radii, situated exactly like those of a regular hexagon.

205. Descartes, to explain this phenomenon, thought that the moleculæ of water being spherical, six globules of this water would first arrange themselves about a seventh, and would then serve as points of attachment to rows of similar globules directed according to lines which would pass through the centres of the former and through that of the middle globule. But this explication resembles many others which bring the fact to them, instead of being accommodated to the fact itself.

206. Mairan, in his Dissertation on Ice, where there are to be found a series of very careful observations, combined with a theory which might then be called better, confined himself to regard the angular disposition in question as the effect of a certain tendency depending on the figure of the moleculæ, which he presumed to be constituted of less spires; and he cited, among other examples which he produces to support

his opinion, that of the cubic pyrite, whose faces are striated alternately in three directions perpendicular one to the other*. This pyrite is, according to him, only an assemblage of spires or needles appropriated, in themselves, to produce these intersecting directions: but we have proved since† that the striated pyrite is, like others, an assemblage of cubic moleculæ, and ought to be regarded as the commencing crystallisation of the dodecaëdron with pentagonal planes (101).

It might rather be presumed that the particles of ice are regular tetraëdræ, composed of octaëdræ, by an arrangement similar to that which obtains in fluat of lime, or fluor spar‡, since the congelations which present indices of regular forms have a marked relation to the metallic dendritæ, which we know to be assemblages of implanted octaëdræ, whose structure resembles that of the spar alluded to; these have the same traits on both parts, the same indentations, the same appearances of equilateral triangles at the extremities.

But, such is the structure of the regular octaëdron, that if it be cut parallel to two of its opposite faces, and at equal distances between them, there will be exposed to discovery a regular hexagon, and that, moreover, six of the component tetraëdræ have each one of its faces situated on the plane of this hexagon. If therefore it be supposed that rows of little crystals are implanted, which, by proceeding from different sides of the hexagon, have their analogous faces on a level with it, which is nothing else than a continuation of an effect in the direction of the structure, these rows will necessarily form between them angles of 60° or of 120°, according as they spring from the adjacent sides of the hexagon, or from the sides taken two by two. It may even be imagined that the crystal

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* Pa. 156 et seq.

† Traite de Miner, t. IV. pa. 75.

‡ Ibid., t. II. pa. 249.

situated at the origin of these different rows is a portion of an octaëdron terminated by a hexagon: for it is not rare to meet with these portions of an octaëdron even among isolated crystals. As for the rest, that which is proposed here is no more than an hypothesis, to which we only attach the degree of value that it appears to possess, as being deduced from analogy, and indicated by observation.

207. We have several times spoken of the degree of congelation, and we have denoted it by the term where either ice commences thawing, or liquid water begins to congeal, the liquor of the thermometer answering to zero; this it is which always obtains effectively. But it does not follow that the temperature of water cannot descend below zero without such water congealing. Fahrenheit first observed, and it was not without surprise, that water contained in a glass phial of which the tube was closed at top, retained its fluidity after having been exposed, during a day and a night, at a temperature greatly inferior to the term of congelation. Having broken the point of the tube, he immediately saw a multitude of little pieces of ice forming in the midst of the water, and he attributed this effect at first to the contact of the air; but another time when he was carrying a similar vessel in which the water was still liquid, he was drawn from his error by an accident singular enough; by making a false step, which produced in the water an agitation succeeded by a sudden congelation.

This effect is analogous to that which occurs in the crystallisation of salts. A slight motion communicated to the vessel in which a saline solution was contained, wherein nothing appeared though it had previously passed the point of saturation, sufficed to determine, at once, the rise of a multitude of little crystals.

We may conceive that, in this case, the agitation of the liquid, at the same time that it assists the saline cooled below its new point of congelation, remaining always liquid; and he determines the temperature which obtains in every particular case.

210. To complete the sketch of all the circumstances relative to this object, we shall remark that there are here two distinct effects which depend upon caloric: in the first place the temperature of the liquid is depressed below zero, because the surrounding bodies deprive it of caloric by their preponderant affinity for that fluid; but when once water is disposed to congeal, by virtue of any cause whatever, it disengages particularly the quantity of caloric which ought to be developed in order that the congelation may have place.

211. It is known that congealed water absorbs in thawing 60° of heat: for, if there be mixed together a kilogramme of water at 60°, and a kilogramme of ice at zero, all the heat of the water will be employed in melting the ice (139): by a contrary effect a mass of water which is congealed developes 60° of heat.

Hence we may explain why it is that water, whose temperature has descended below zero, remains liquid: for if the circumstances are such that the caloric which is developed by the effect of the congelation should be very slow in communicating itself to the surrounding bodies, there will result a cause of retardation with respect to the congelation itself; since that the more considerable the portion of caloric which we suppose developed, and which would tend to remain in the mass, the more it will be contrary to one of the necessary conditions of the congelation; namely, that the temperature does not become elevated above zero, because at that term ice commences thawing.

This obstacle, which the slow transmission of the caloric presents to the congelation, is such, that if we suppose the water exactly contained in a vessel that is a non-conductor of caloric, it cannot be entirely congealed, on this mathematical hypothesis, at a temperature of less than 66$\frac{2}{3}$ degrees below zero; supposing, with Mr. Kirwan and many other philosophers, that the specific heats of ice and water in the liquid state are in the ratio of 9 to 10: for the quantity of heat developed by the water during its congelation is, as we have said, equal to that which would raise the temperature of that liquid to 60°. But when the developement of that quantity of heat, which we suppose to remain entirely in the water, has determined the point of the congelation, the ice is in the same case as if, its temperature having been originally of a number *n* of degrees below zero, it were elevated to zero by an augmentation of heat capable of causing the temperature of the water to rise 60 degrees. Therefore, since the elevations of temperature of two bodies by the same augmentation of heat follow the inverse ratio of the specific heats (126), we have this proportion, $60^\circ : n :: 9 : 10$, which gives $n = \frac{10}{9}$ of $60^\circ = 66^\circ\frac{2}{3}$; that is to say, the elevation of temperature which gives birth to the congelation in the present hypothesis would be $66^\circ\frac{2}{3}$, or, in other terms, the temperature of the water must have been originally of that number of degrees.

If, in the same hypothesis, the temperature were nearer to zero, there might still be a congelation, but solely with regard to a part of the water; and we might find an infinitude of possible cases of equilibrium, by supposing that all which would be susceptible of congelation became congealed in effect; so that we might determine, by the aid of a simple computation, the part which would be congealed by each degree of temperature. But these circumstances do not obtain in nature, because the surrounding bodies always take their part of the developed caloric*.

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* See the Memoir published by Lavoisier and Laplace among those of the Academy of Sciences, 1780, pa. 355 et seq.

212. With respect to the congelation occasioned by the agitation of the liquor, Sir Charles Blagden, by trying motions of different kinds, has been able to distinguish those whose effect is most likely to command, in some sort, the sudden reunion of the aqueous particles. He has observed that in general this effect depends upon a particular agitation produced in the liquid, rather than upon a rapid motion impressed upon all the mass. Thus we may succeed by striking lightly with the bottom of the vessel the table which supports it, or by striking against the interior parts of the said bottom with a tube or with a feather. But of all the exciters of congelation, that which most rarely fails in its effect is a small piece of wax with which the interior parts of the vessel are struck in some points inferior to the upper surface of the water, so as to generate a species of sonorous vibrations. At the same instant there will be seen a crust of ice at the part of the vessel situated beneath the wax.

213. While water passes to the state of ice, its volume undergoes different variations, the progress of which deserves to be attentively traced. If we expose to frost a glass vessel filled with water to about the middle of its height, we shall first see that water descend in proportion as it cools; arrived at a certain term it will there remain stationary for some seconds, after which it will begin to mount; so that at the moment of its congelation it will be found above its first level.

Hence it is manifest that the volume of congealed water is greater than that of the same water in its liquid state. It follows that the specific gravity of water is diminished by congelation; which indeed is farther proved by the property which flakes of ice have of swimming on the water which carries them.

214. The observation which we have just cited would immediately indicate that the dilatation of the

water, in the state of ice, was not produced suddenly, as though by a hasty leap, at the very moment of congelation, but that it commenced sooner; in such manner that the point of the greatest contraction was at some degrees above the zero of the thermometer.

It may be objected, notwithstanding, that we have here an effect which was only apparent, and which arose from this, that the glass, being condensed at the same time with the water, during the cooling, would experience at the approach of congelation a contraction which was proportionally greater than that of the water. It is thus that the fact has been explained by several philosophers, who have thought that, in this case, the water appeared solely to acquire an extension of volume which was owing to the excess of the contraction of the glass above that of the water itself.

But the experiments made by Lefevre-Gineau, with the cylinder which he used in determining the new unit of weight (71), leaves no room to doubt that the dilatation of the water is real. This philosopher has weighed the cylinder now adverted to, at different times and with an extreme care, while the temperature of the water in which that instrument was immersed varied as it approached the term of melting ice: He has found that the cylinder always began to lose more of its weight, in proportion as the water cooled, and that to about the fourth degree above the zero of the centigrade thermometer, which answers to 3⅕° upon Reaumur, or 39⅕° upon Fahrenheit's thermometer. Beyond that term the loss of weight diminished as the temperature approached the point of congelation. In the first case the force of the water to sustain the cylinder continued to augment; whence it follows that the liquid contracted more and more. The same force diminished in the second case, which indicated a dilatation in the liquid: and thus, the *maximum* of density corresponded very nearly with the fourth degree of heat upon the centigrade thermometer.

215. The ordinary motion of the thermometer is always somewhat complicated with this double effect of the temperature, to dilate or contract at the same time both the liquid and the glass which contains it; so that the variation of the mercury appears less than it really is; but this difference does not influence the results of the common observations, since it is supposed that between the two fixed points to which the construction of the thermometer is referred, the degrees of dilatation or of contraction, both of the mercury and the glass, conform sensibly to the same ratio.

216. According to the observations of Blagden, the dilatation to which water is subjected by the effect of cooling, after a certain term, is susceptible of a farther augmentation when the liquid continues to cool below the point of congelation, without passing to the solid state. It even appeared to this philosopher that the expansion increased in its progress, so as to be much greater towards the latter degrees of cooling than it had been at the commencement *(i)*.

(*i*) The discovery of the singular exception furnished by water to the general law of the expansion of bodies by heat and contraction by cold, was first made by Dr. Croune: but on announcing it to the Royal Society, in 1683, Dr. Hooke expressed his doubts, and accounted for the phenomenon described by Croune upon the hypothesis mentioned in art. 214. Since then, the particulars of this remarkable anomaly have been farther investigated by Slare, De Luc, Blagden, Rumford, Lefevre-Gineau, Hope, and Dalton. The principal circumstances as stated by Dr. Hope (Edinburgh Phil. Trans.) are these: When heat is applied to water ice-cold, or at a temperature not far distant, it causes a diminution in the bulk of the fluid. The water contracts and continues to contract, with the augmentation of temperature till it reaches the 40th or 41st degree on Fahrenheit's thermometer. Between this and the 42d or 43d it suffers scarcely any perceptible change; but when heated beyond 48° it begins to expand, and increases in volume with every subsequent rise in temperature. The change happens in a reverse order during the abstraction of caloric. Warm waetr as it cools, shrinks as other bodies do till it arrives at 43° or 42°, when it suffers a loss of about 2 degrees without any alteration of density.

217. A remarkable circumstance which accompanies the formation of ice, is the disengagement of the air contained in the water. This air escapes under the form of little bubbles, several of which uniting together form bubbles more considerable, the diameters of them being often six lines or even an inch in length. Sometimes these bubbles are in the form of little tubes, more or less inclined with regard to the axis of the vessel in which the congelation is carried on: this is especially observed in distilled water which passes to the state of ice.

218. The augmentation of volume experienced by this ice may be attributed in part to the extrication of the air. For it may here be, relatively to the water and air, as in regard to certain substances which ap-

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But when farther cooled, it dilates continually as the temperature falls, till congelation actually commences.

Dr. Hope concluded from his experiments that the greatest density lies between 39½ and 40°, differing but little from the result of Lefevre-Gineau stated by M. Haüy. They likewise indicate the nature of the change, but not its amount: the doctor is inclined to think that the amount of the dilatation by cold is inferior to that occasioned by heat.

But Mr. Dalton has endeavoured to shew (Nicholson's Journal, Nos. 54 and 56) that the results of Dr. Hope's experiments are explicable on the supposition of water being densest at 36° of Fahrenheit, and no other. Mr. De Luc was the first who observed that the expansion of water on each side the temperature of greatest density, is the same quantity for the same number of degrees, whether of increase or diminution of temperature. Mr. Dalton has lately examined this fact with greater attention than formerly, and finds that it is accurate, except that the expansion for degrees *below* the stationary point is always somewhat more than for a corresponding number of degrees *above* the said point. This gentleman concurs in opinion with Dr. Hope, that water may in certain circumstances continue fluid below its freezing point, even as far as 25°; a statement which is certainly admissible.

After all, the exact situation of the temperature of greatest density does not seem completely decided, though the general facts relative to the expansion and contraction are incontrovertible. It likewise remains for future philosophers to enquire, whether this manner of change in density is peculiar to water, or whether (as has been suggested by Mr. Nicholson and others) it does not extend to all such fluids as expand by congelation, if not to other liquids. Tr.

pear mutually to penetrate on being mixed, so that the sum of their volumes, taken separately, was greater before the mixture.

But water which has been purged of air as completely as possible, before it was congealed, does not abandon its property of perceptibly augmenting its volume: hence, this effect depends in great part upon a new arrangement assumed respectively by the integrant moleculæ of the liquid, on re-uniting by their force of affinity; and it is known that this effect is not peculiar to water. Reaumur has observed that iron acquires a more considerable volume by the cooling which succeeds the fusion of that metal and congeals it; while mercury, on the contrary, in the same case, is contracted by a very perceptible quantity.

219. Mairan ascribes the dilatation of congealed water to a species of disorder produced by the more or less rapid motion which agitates the particles while they are uniting with one another. It results, according to his hypothesis, that they intersect and embarrass one another mutually under an infinitude of different positions, and leave little vacuities between them, which tend to make them occupy a greater space than in the state of simple liquidity.

It may easily be conceived that, all other things being the same, a confused crystallisation by giving place to a multitude of little interstices which would have been filled in the case of a crystallisation more slow and gradual, may tend to augment the volume of the solid mass produced by that operation. But it appears that the sole act of crystallisation is, of itself, at least relatively to certain substances, and particularly with regard to water, an immediate cause of augmentation in volume. Such, in these cases, is the figure of the moleculæ, combined with other circumstances, that, to conform to the variety of arrangements which determine their new respective positions, they are forced to unfold themselves (as it were) in a space more extended than that which they required in the state of liquidity.

220. Mairan having sought the specific gravity of ice, by means of the hydrostatic balance, has found that the volume of the water was increased about $\frac{1}{14}$th by the congelation: but this effect varies according to circumstances; and as it arises in general from a particular arrangement assumed at once by the particles of water, in virtue of the affinity which, in this case, acts very powerfully to fix them, one may see a little how there may result a very considerable expansive force in the ice. Hence the efforts it exerts against the sides of the different vessels which may contain it. If the vessel be of a flat shape, and present a large opening, the force of the ice exerts itself in part upon the superior crust, which it lifts up towards the middle, and makes it take a convex figure; so that the sides of the vessel having only to sustain the residue of the same force, commonly oppose to it a sufficient resistance: but if the vessel be narrow, it rarely happens that it is not broken by the effort of the ice, which then acts almost entirely in the lateral directions; and there is scarcely any person who has not more than once seen vessels in ordinary use rendered quite unserviceable by the congelation of the liquid which has been permitted to remain in them.

221. Several philosophers have been desirous to experience how far this force of expansion might be carried. An iron gun of an inch thickness, filled with water and exactly closed, having been exposed by Buot to a strong frost, was found to be burst in two places at the end of 12 hours. The Florentine philosophers were able, by means of the same cause, to burst a sphere of very thick copper; and Musschenbroek

having calculated the effort which would occasion the rupture, found that it would be capable of raising a weight of 27720 pounds *(j)*.

222. When after a thaw the return of a frost converts into ice the water which the earth had imbibed, this ice, which has undergone an augmentation of volume, locks up the growing vegetables by the extremity of their root, and fatally attacks that part by which they were enabled to suck in the nutritive juices furnished by the earth *(k)*. A sharp frost which prevails during the spring, likewise produces preju-

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(*j*) Colonel E. Williams, of the Royal Artillery, when at Quebec in the years 1784 and 1785, made many experiments on the expansive force of freezing water: the principal results of which have been published in vol. II. of the Edinburgh Philosophical Transactions. He filled all sizes of iron bomb-shells with water, then plugged the fuze-hole close up, and exposed them to the strong freezing air of the winter in that climate; sometimes driving in the iron plugs as hard as possible with a sledge-hammer; and yet, though they weighed near 3 pounds, they were always forced out by a sudden expansion of the water in the act of freezing, like a ball impelled by gunpowder, sometimes to the distance of between 400 and 500 feet: and when the plugs were screwed in, or furnished with hooks or barbs, by which to lay hold of the inside of the shell, so that they could not possibly be forced out; in that case the shell was always split in two, though its thickness of metal was about an inch and three quarters. It is farther remarkable, that through the circular crack, round about the shells where they burst, there stood out a thin film or sheet of ice, like a fin; and in the cases where the plugs were projected by freezing water, there suddenly issued from the fuze-hole a bolt of ice of the same diameter, and stood over it sometimes to the height of 8 inches and a half. Hence we need not be surprised that excessive frost should cause the ice to split rocks, and other solid substances. Tr.

(*k*) Frosts often occasion a scantiness of water in our fountains and wells. This is sometimes erroneously accounted for by supposing that the water freezes in the bowels of the earth. But this, as Dr. Robison remarks, is a great mistake: the most intense cold of a Siberian winter would not freeze the ground two feet deep; but a very moderate frost will consolidate the whole surface of a country, and make it impervious to the air; especially if the frost have been preceded by rain, which has soaked the surface. When this happens, the water which was filtering through the ground is all arrested and kept suspended in its capillary tubes by the pressure of the air. Tr.

dicial effects, even in the interior of plants which had already commenced their developement. The sap, composed in great part of water, is dilated by congelation, while on the contrary the fibres of the plant experience a contraction; there results a kind of rents and fissures which occasion a derangement in the organisation.

223. The same cause extends its destructive influence even to organic beings. The stones which have been wetted before freezing exfoliate; marbles which are blown to pieces by means of the explosion of powder, and in which crevices are formed, by the shock they have undergone, are, in the same case, liable to split in various places. It is well that artists should know the cause of these accidents, as they may often have it in their power to prevent them.

224. Water which holds a salt in solution allows it to be precipitated when it is converted into ice. In some countries of the north, the inhabitants profit by the cold of the atmosphere, as by a preparatory mean, to extract the salt from sea water. They pour water into wide receptacles formed for that purpose so as to make very shallow strata. A part of this water, by its congelation, abandons the saline moleculæ which become concentred in the portion still fluid; so that the latter only needs to be exposed to a moderate heat in order that its evaporation may permit the salt with which it is charged to crystallise.

On the Congelation of Mercury.

225. Mercury is, next to water, that of all the liquids whose congelation has given place to the most interesting observations. This substance, which appears to play a part so singular in nature, is in reality

only a metal capable of entering a state of fusion by a temperature incomparably less elevated than that which ordinary metals require to melt them, which merely indicates that the degree of cold necessary to render it solid is much beneath the zero of our thermometers *(l)*. Indeed Delisle and Gmelin, while in Siberia, saw the mercury congeal naturally in the thermometers which they made use of. But this phenomenon was yet unknown, or at least involved in doubt, when, in the month of December, 1759, Mr. Braun, member of the academy of St. Petersburg, having availed himself of a very severe cold which then prevailed in that country, and which was measured by —34° of Fahrenheit (answering to $29\frac{1}{3}$° below the zero of the thermometer in 80 parts), was able, by the aid of a mixture of pounded ice and nitric acid, to make the mercury in the tube of his thermometer descend to —69° of Fahrenheit (—$44\frac{8}{9}$° of the thermometer in 80 parts). He then perceived that a part of the mercury was congealed, and encouraged by this first success, he pursued his experiments, substituting snow for ice; the mercury continued to descend, and arrived, in the last experiment, at —352° of Fahrenheit (—$170\frac{2}{3}$° of the thermometer in 80 parts). Mr. Braun having withdrawn his thermometer from the mixture, and carefully examined the ball, could not perceive any fissure; at the same time he saw that the mercury was immoveable, and continued so for about twelve minutes. Some days after he repeated the experiment with Æpinus; and having again succeeded in fixing the mercury, he broke the ball of his thermometer, and took out the metal under the form of a solid shining mass, which extended ~~itself~~ by percussion, and yielded a blunt sound, similar to that of

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(*l*) The reader will recollect that by the term "*our* thermometers," M. Haüy means Reaumur's and the centigrade thermometer, whose zero stands at the point of thawing ice. See art. 163. Tr.

lead, which also it nearly approached with respect to hardness*.

It could not then be doubted that mercury was susceptible of a congelation, properly so called; but that was far from knowing the true degree of cold which would suffice to produce it. Mr. Braun, and several other philosophers, have thought this degree to be much lower than it was in fact, by confounding two effects that are very distinct, namely, the temperature of the metal at the moment of congelation, and the considerable contraction which it experienced when it became fixed; a circumstance with respect to which it is contrasted with water, which, as we have seen, experiences on the contrary a dilatation, before it reaches the term where it becomes congealed.

226. The idea which ought to lead to the determination of this limit, which is, with regard to mercury, what the zero of the thermometer in 80 parts is relatively to water, occurred at the same time both to Black and to Cavendish, two men the most formed by their talents and pursuits for such a coincidence. They applied the same reasoning to mercury as to water itself, the temperature of which is constant, as to sense, from the moment when that liquid begins to be congealed to that wherein all the mass has become solid. Mr. Cavendish, to render still more striking the analogy suggested by this observation, made the application to metals that are easily fusible, such as lead and tin; and he found that a thermometer immersed in either of these metals remained stationary during all the time of the passage from liquidity to solidity†.

The apparatus contrived for the experiments relative to mercury, consisted of a small mercurial thermometer, which he introduced into a glass bottle whose

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* Nov. Commenta. Acad. Scient., Imper. Petropol. tom. XI.

† Philosophical Transac. 1783, pa. 313.

larger part was filled with the same metal, and surrounded by a mixture of frigorific substances. He saw the mercury descend progressively in the tube of the thermometer until the moment when the congelation of that in the vessel commenced, and then observed it to continue at that point all the time of the operation of freezing. He found that the term then indicated by the mercurial thermometer answered to about —39° of Fahrenheit (—31½° of the thermometer in 80 parts). If he had employed a thermometer of alcohol, constructed according to the same division, he would have found nearly 80° below zero for the corresponding term.

227. The experiment of the congelation of mercury has been several times repeated at Paris of late years. Those persons who have had the courage to take into the hand the congealed metal, have experienced a painful sensation, of which they could not give a more just idea than by comparing it to that produced by a severe scalding. Nothing could more completely justify the language of the poets, who, to depict a very sharp coldness, have called it a *scalding cold (m).*

(*m*) In the year 1780, Mr. Von Elterlein, of Vytegra in Russia, froze quicksilver by natural cold. On the 4th of January, 1780, the cold being increased to —34 of Fahrenheit that evening at Vytegra, he exposed to the open air 3 ounces of very pure quicksilver in a china tea-cup, covered with paper pierced full of holes. Next day, at 8 in the morning, he found it solid, and looking like a piece of cast lead, with a considerable depression in the middle. On attempting to loosen it in the cup, his knife raised shavings from it as if it had been lead, which remained sticking up; and at length the metal separated from the bottom of the cup in one mass. He then took it in his hand to try if it would bend: it was stiff like glue, and broke into two pieces; but his fingers immediately lost all feeling, and could scarcely be restored in an hour and a half by rubbing with snow. At 8 o'clock the thermometer stood at —57; but by half after 9 it was risen to —40; and then the two pieces of mercury which lay in the cup had lost so much of their hardness, that they could no longer be broken, or cut into shavings, but resembled a thick amalgam, which, though it became fluid when pressed by the fingers, immediately afterwards resumed the consistence of pap. With the thermometer at —39, the quicksilver

228. Various metals when returning to solidity, after having been melted, undergo a regular crystallisation. The caloric acts here with regard to a metal in fusion, as do ordinary liquids with respect to a salt which they hold in a state of solution. In both cases it is the retiring of the substance at first interposed between the metallic or saline particles, which permits them to approach one another and unite under geometrical forms, when such withdrawing is made slowly enough to give them time to assume the arrangement which accords with the laws of crystallisation.

The earliest indices which were observed of these phenomena, appear to have been those species of ramified stars which are formed upon the surface of antimony. It was to the eyes of alchemists that these stars first presented themselves, and they explained the fact consistently with their art: it was a star of happy influence, which predicted to them the metamorphosis of antimony into gold.

The experiments performed upon bismuth, by Brongniart, professor to the museum of natural his-

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became fluid. The cold was never less on the 5th than —28, and by 9 in the evening it had increased again to —33. This experiment, as well as those of Mr. Cavendish, seems to fix the freezing point of mercury at —39 or —40 of Fahrenheit's thermometer, or 40 below 0; which is 72° below the freezing point of water.

On this subject, a variety of curious facts are recorded in Hutton's Dictionary, art. FREEZING *Mixture*; also in the Philosophical Transactions, vol. 51, pa. 672; vol. 52, pa. 156; vol. 66, pa. 174; vol. 73, pa. 303 and 325; vol. 76, pa. 241; vol. 77, pa. 285; vol. 78, pa. 43; and several others, particularly vol. 79, pa. 199, &c.; being experiments on the congelation of quicksilver in England, by Mr. Richard Walker, where he proves that mercury may be frozen not only in England in summer, but even in the hottest climate, at any season of the year, and without the use of ice or snow. Indeed, the experiment of the congelation of mercury has of late been frequently repeated at London, Cambridge, Oxford, Edinburgh, and most of our principal towns: the chief circumstances being uniformly found to correspond as nearly as can be expected with what is stated by M. Haüy, and in this note. TR.

tory, have offered the first example of a metal converted into projecting crystals, by a process similar to that which Rouelle had employed in relation to sulphur, and which consists in leaving the surface of the metal to congeal, then in piercing this incrustation, and emptying the liquid from the hollow part. Afterwards, when this is broken, subsequent to entire refrigeration, the cavity has been found wholly hung (as tapestry, *tapissée)* with crystals, which present, according to circumstances, groups of octaëdræ or of cubes disposed upon lines respectively perpendicular, and re-entering like the contour of a volute.

Some have thought that the vacuity left by the metal which was poured out of the crucible, by giving access to the air favoured the production of crystals. But the truth is, that these crystals are forming at the middle of the metal even while in fusion, by the mutual approach of the parts which have first cooled. It is, with respect to this metal, nearly as with water which is congealing in the midst of other water still fluid. Nothing more is done by partly emptying the crucible, than uncovering the crystals already formed, and disengaging them from the surrounding metallic matter, with which they would make only one solid mass after the refrigeration. We may assure ourselves of this by taking out with the point of a pen-knife the crust which is formed at the surface; on removing this we shall find beneath it crystallisations similar to those which we have described. Bismuth is one of the metals which is most easily applicable to this kind of observation.

3. *On Water in the State of Vapour.*

229. We have before spoken (135) of a phenomenon which is presented as the ultimate result of the accumulation of caloric between the moleculæ of a body, and which consists in the conversion of those moleculæ into an elastic fluid. These fluids are distributed into two classes: one class comprehends those which retain their elastic fluidity under the strongest pressures to which we can subject them, and at all the known degrees of refrigeration: they have received the name of *aeriform fluids*, borrowed from that of the atmospheric air, which seems to possess the first rank among them. They are likewise called *permanently elastic fluids* or *gases*. In the other class are comprised such elastic fluids as easily lose that state by pressure or by cooling: among this number are common water, alcohol, ether, &c. These fluids have been called *vapours*, or *non-permanent elastic fluids*; and the phenomenon which consists in the passage of a body from the state of liquidity to that of vapour, takes the name of *vaporisation* when it is solely due to the action of caloric, and that of *evaporation* when the air intervenes in its production, by the affinity which it exercises towards the particles of the vapour. We shall limit ourselves in this place to that which concerns the first of these effects, and shall especially consider it in relation to water. As to the other effect we shall reserve the more particular explication of it till we treat of the properties of atmospheric air.

230. Ebullition is, in general, with respect to liquids, the sign of commencing evaporation. It is announced by the bubbles which proceed from the

vessel, and succeed one another rapidly in traversing the liquid, the surface of which they raise up. These bubbles are nothing else than portions of liquid already converted into vapour by the action of the caloric, and which tend to escape in virtue of their elastic force. When the ebullition is produced by means of fire which we suppose to act beneath the vessel containing the liquid, the inferior stratum of this latter receiving immediately the caloric which introduces itself into the vessel, should also be the first that is vaporised. But the same effect obtains under a receiver where a vacuum has been obtained, in order to determine the ebullition by a much lower temperature than that which would be necessary under the pressure of the atmosphere (141). In this case the depression of temperature occasioned by the rarefaction of the air included under the receiver (148) acts upon the superior lamina, and from one to another upon the following, by degrees continually diminishing; whence it follows that the lowest bed of the liquid which retains the most heat must still furnish the first bubbles.

231. The different temperatures have been observed, to which correspond the ebullition of certain substances by a pressure of 28 inches (29·9 inches English) of mercury. According to the enquiries made by Deluc relative to alcohol, the ebullition of that liquid commences at 67 degrees on the thermometer of 80 parts (182 ¾° on Fahrenheit). Citizens Laplace and Lavoisier have found that, in the same case, ether commences ebullition (*n*) at

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(*n*) These temperatures do not agree with those which result from the most accurate experiments in England; the boiling points of a number of liquids under a medium atmospheric pressure have been stated by Dr. Gregory thus: Ether, 98° on Fahrenheit; Ammonia, 140°; Alcohol, 176°; Water, 212°; Muriat of lime, 230°; Nitric acid, 248°; Sulphuric acid, 500°; Phosphorus, 554°; Oil of turpentine, 560°; Sulphur, 570°; Linseed oil, 600°; Mercury, 660°. If the pressure be diminished the liquor boils at a lower temperature: if it be increased a higher temperature is necessary to produce ebullition. The late professor Robison concluded that in a vacuum all liquids would boil at about 145° lower

32 or 33 degrees (104° or 106° on Fahrenheit). Another experiment of the same philosophers shews with what rapidity ether dilates itself by evaporising in a vacuum. The experiment consists in covering with a stratum of this liquid the surface of the mercury contained in the cistern of a common barometer, then in slightly inclining the tube and raising it a little, so that it may remain partly immersed, and that this little motion may cause a drop of ether to be introduced into the lower part of the tube: this drop will raise itself through the column of mercury; when arrived at the surface it will be converted into vapour, and at that instant the mercury will be depressed by a considerable quantity.

232. But the vapour or steam of water is, of all the elastic fluids that have been submitted to experiment, that which has furnished the most interesting results, by the application which has been made of its expansive force to mechanics, as we shall soon shew a little more at large.

The vaporisation of water commences, as we have seen, at 80° on Reaumur's thermometer, under the medium pressure of the atmosphere; and we have shewn, moreover, that the temperature remains the same during all the time of the conversion of the liquid into vapour (135). But this uniformity of heat obtains no longer than while the vapour has liberty to escape as it is generated; for, if water which becomes vaporised is contained in a vessel

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than in the open air under a pressure equivalent to 30 inches of mercury; thus alcohol would boil in vacuo at 34° and water at 67°: yet Dr. Thomson affirms that water in vacuo boils at 90°. Water confined in Papin's Digester may be almost heated red hot without boiling. The mixture of various salts with water affect its boiling point considerably; as appears from Mr. Achard's experiments recorded in the *Berlin Transactions* for 1785. He found that a saturated solution of muriat of soda raised the boiling point 10·35°; one of muriat of ammonia, raised it 9·79°; one of carbonat of potass, raised it 11·2°; while a small quantity of borax, lowered it 1·85°; Ditto of sulphat of magnesia, lowered it 2·473; and sulphat of lime in any proportion, lowered it 2·02°; it may not be amiss for those who have proper opportunities to pursue this kind of enquiry, as it may lead to a saving of fuel in steam-engines. TR.

which does not permit it to have any outlet, then the vapour, by accumulating in the upper part of the vessel, exerts upon the water still liquid a pressure which when arrived at a certain term will oppose itself to the effect of the elastic force of the caloric to vaporise other water; so that the caloric accumulates in its turn, either in the liquid, or in the vapour itself, and the temperature continues to rise much beyond the term of 80°.

Upon this principle was constructed the machine so well known by the name of *Papin's Digester*, and of which that philosopher published a description at Paris in 1682, under the title of *A Machine proper to soften bones and convert them into soup.* The heat that is produced in this machine is so powerful, that the water it contains becomes capable, not only of dissolving the bones, and extracting the gelatinous part; but also of melting lead, and even copper, as different philosophers have observed.

233. When vaporised water meets with neighbouring bodies whose temperature is much lower than its own, it instantly yields to them a great part of the caloric which maintained it in the state of an elastic fluid, and re-assuming the liquid state, adheres to those bodies under the form of a humid cover or dew. Hence that lively impression of heat which is felt by the hand or other part of the body which is suddenly exposed to the vapour of water.

234. The extinction of fire produced by the injection of water upon the inflamed body, is no other thing in the opinion of the vulgar than the effect of a kind of struggle between two hostile substances, the one of which arrests the progress of the other. The true explication of the phenomena is that the water intercepts, on one part, the contact of the air with the combustible body, and on the other takes up, by its vaporising, a part of the caloric necessary to produce such a separation between the particles of that body as disposes it to unite with the oxygen of the air.

235. When water still liquid is heated more and more, its dilatations vary in a ratio sensibly greater than the augmentations of heat, and this difference is especially denoted at the approach of ebullition. This may be conceived by considering that when the distance between the aqueous moleculæ has reached a certain point, through the elastic force of the caloric, the affinity which only acts very perceptibly when near to contact, ought always to diminish more rapidly, even supposing equal augmentations of heat; so that the dilatations will, on the contrary, increase in a very high ratio. Nevertheless the total effect of the dilatation, from the term of thawing ice to that of boiling water, is limited to an increase of about $\frac{1}{18}$ of the volume of water. But at the moment of ebullition, the dilatation makes a sudden leap; and according to the most recent experiments, the vapour expands itself rapidly into a space one thousand seven hundred and twenty-eight times greater than that which the water occupied in its state of simple liquidity, in such manner that a cubic inch of this water produces a cubic foot of vapour (*o*).

236. It is to this great expansion of vaporised water that the effect of the æolipile is to be ascribed, which was so long attributed to the dilatation of the air. This name is given to a metallic vessel in form of a hollow pear, the tail or stalk of which is a narrow tube. The vessel is heated in order to expel a great part of the air which it

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(*o*) There is a considerable difference in the results of experiments performed with a view of determining the ratio between the densities of water and the vapour of water at the boiling point. Some philosophers state it at 3000 to 1, others at 2655 to 1, others at 2000 to 1, M. Haüy as above at 1728 to 1, while in art. 317, he gives 1600 to 1 as the ratio, under the medium atmospheric pressure. It is probable that the earlier experiments on this point were made without paying much regard to the variation of atmospheric pressure. However since the density of water is to the medium density of air as 820 to 1, it may be safely asserted that aqueous vapour is twice as light as air; of consequence the latter as it becomes saturated with such vapour, becomes specifically lighter, so as to occasion its elevation in the atmosphere. Tr.

contains; then the orifice of the tube is plunged in water until that liquid is introduced by the pressure of the surrounding air into the vessel, so as to fill a half or two thirds of it. Then the æolipile is placed with its bottom turned downwards, upon burning coals, and the fire is animated until a violent blast of air proceeds from the orifice of the tube. Lastly, the æolipile is so inclined that its tube is situated vertically, the orifice upwards, and the heating of it is continued. In a short time the part of the water still liquid, being driven on by the vapour, will dart forward in a jet which sometimes rises to the height of 8 metres, or about 25 feet. When the liquor is alcohol, we shall have a jet of fire by presenting a lighted torch at about a decimetre (3 or 4 inches) above the origin of the jet.

237. But the vapour or steam of water becomes capable of producing much more astonishing effects by its expansive force. There are, in the Memoirs of the Paris Academy of Sciences for the year 1707, some observations communicated by Vauban, from which it results that 140 pounds of water converted into vapour, would produce an explosion capable of blowing up a mass of 77000 pounds, while 140 pounds of powder could only produce a similar effect upon a mass of 30000: so that the force of the steam of water was more than double that of the gunpowder.

On Steam Engines.

238. Effects so powerful as those of which we have just spoken could not long remain sterile in supplying the necessities of the arts: they furnished a new moving force to mechanics which it required no ordinary genius to have created and to have measured its energy. This science during a long time had only employed water as a moving force, by availing itself of its natural course, or by judiciously managing its fall, so as to subject to it the

operation of machines which it regulated by an impulsion continually renewed. The experiments made upon the force of water reduced to vapour gave birth to the idea of applying that vapour so much the more advantageously to the same purpose, because independently of its great energy, it may be transported wherever it is called for by the interests of commerce and of industry.

239. The execution of steam-engines has had, like that of all other machines, its different epochs, to which successively corresponded new degrees of perfection. To diminish as far as possible the quantity of vaporisation requisite for the effect in contemplation, and to make a moderate use of the combustible; to combine with this chief economy that of substance, and of workmanship, by contracting the dimensions of the pieces, without diminishing their utility; to prevent explosions, by the wisest precautions adopted in the management of an agent whose power becomes destructive when it is not limited: these are in general the objects which have fixed the attention of engineers, and have excited among them a laudable kind of rivalship. We shall confine ourselves to the means of perfection which are most manifest, and shall only so far enter into the description of machines as will be necessary for understanding the principal effect.

All the motions of the Steam-engine derive their origin from the operation of a piston which is raised and depressed alternately in a cylindrical tube, communicating with a caldron or boiler in which the steam is formed by the action of a fire kept up beneath it. The manner in which the vapour contributes to the operation of the piston is varied according to different methods; and our object is especially to compare those methods, and to shew the fresh advantages which they have brought with them as they have succeeded one to another.

240. The first method whose success was announced by a general eagerness to imitate it, is that which is commonly attributed to an Englishman named Savery, but

the invention of which is due to two other Englishmen, viz. Newcomen and Cawley. The machine which was really contrived by Savery had much similarity to the fountain of compression which we shall describe under the article air; and in which that fluid condensed exerts upon the water a pressure that determines it to spout forth by a canal which offers it a free issue: all the difference consisted in this, that Savery substituted the force of steam for that of compressed air. Savery, by being associated with Newcomen, seized the honour of this discovery, and his ambition soon eclipsed the simple and modest man who confined the pleasure to his own bosom.

To comprehend the operation of the machine in question, let us suppose that the piston is descended to the lowest point of its course; at that instant the communication between the boiler and the bottom of the cylinder is opened by a peculiar motion made by a circle called the *regulator*, which previously closed that communication; thus the steam introduces itself below the piston, and impels it upwards by its expansive force. When it is at the end of its rising stroke, the regulator has returned to its place, and, by means of a cock which opens at the instant, a jet of cold water spouts out of a tube, connected with the cylinder, and striking upon the inferior base of the piston from whence it falls again in a kind of a shower, it condenses the vapour and destroys its effect. Then the atmospheric air which acts by its pressure upon the superior base of the piston, causes it to descend; after which the emission of the steam and the other effects succeed one another afresh, so as to perpetuate the alternate motions of the piston.

The top of the piston rod is connected with one of the extremities of a reciprocating beam, whose opposite extremity gives motion in a contrary direction to the rod of a second piston adapted to a true pump, in which water is raised in the usual way.

This machine has two important inconveniences which were not long before they were perceived: on one hand, the injection of cold water being made in the cylinder itself, cooled its sides; on the other hand it was requisite to keep the upper base of the cylinder always covered with water, either to prevent the drying of the leathers, or to cut off all access of the air into the inferior part of the cylinder where the steam was introduced; whence it happened that the piston during its descent moistened in its turn the sides of the cylinders. To compensate for the effect of the refrigeration produced by the two causes we have spoken of, it was necessary to furnish a greater quantity of steam; whence resulted à double defect of economy, namely, in the employment of the metal to form a boiler which must be of larger capacity, and in the consumption of the combustible.

241. The machine invented by the celebrated Watt combined with the advantage of making these inconveniences disappear, a perfection which seemed to render his contrivance new in all respects. That which principally distinguishes it, is the double employment of the steam, of which one part is introduced beneath the piston, as in the machine ascribed to Savery, and the other above the same piston; in such manner that the interior of the cylinder has not any communication with the atmospheric air, which therefore contributes nothing to the operation of the machine. Farther, the extremity of the reciprocating beam opposite to that which conducts the piston of the steam cylinder, is loaded with a counter weight whose use we shall soon see. Lastly, the bottom of the cylinder communicates with a tube called the *condenser*, which is placed on one side, and in which the condensation is carried on.

Suppose now that the piston has arrived at the highest point of its course, so that there is a vacuum in all the part of the cylinder situated below it, and that the piston is only retained in its position by the action of the counter-weight mentioned above. In this state of things the vapour enters above the piston, and its force preponderating, with regard to that of the counter-weight, causes the piston to descend until it has terminated its stroke. Immediately fresh steam is introduced beneath the piston, and forces it to rise, until an equilibrium obtains between the steam on the different sides of the piston: the elevation is then continued by the action of the counter-weight, which is no longer hindered from obeying the law of gravitation. As the piston rises it presses forward the steam that is above it, and which is thence conducted under the inferior base, to fill up the space left void by its ascension. This motion terminated, the condenser opens, and permits the steam to introduce itself into its cavity, where it is condensed by an injection of cold water. The piston then re-descends and re-mounts alternately, in virtue of a similar combination of different actions produced by the two vapours and the counter-weight.

It is easy to see that this construction is much better disposed than the former, to prevent the superfluous expense of vapour and of combustible occasioned by the cooling of the cylinder. The machine of Chaillot, near Paris, in which it has been adopted, and the execution of which is due to the talents of the brothers Perrier, has for its object to raise the water from a reservoir which communicates with the Seine, to distribute it afterwards into the different quarters of Paris. According to the prospectus published by the authors, this machine can furnish, in the space of 24 hours, about thirteen thousand seven hundred and eleven cubic metres, or four hundred thousand cubic feet of water.

242. We knew of nothing more perfect of this kind, until in 1788, when Betancourt having been at London saw there a new steam-engine executed under the direction of Watt and Boulton. They contented themselves with stating to him that this machine had many advantages over the others; but, for the rest, made a mystery

of the mechanism, and the secret was well guarded by the machine itself; for an observer could do but little more than pass before an assemblage of pieces, some of them entirely interior, the others hidden in part by the disposition of the edifice. Nevertheless Betancourt guessed the principle, and on his return to Paris, he constructed a model in which he made an application of that principle by means equally simple and ingenious.

In this new machine the steam is also introduced both below and above the piston; but the perfection of the mechanism consists in this, that the injection of cold water is repeated on both sides, so that it condenses in their turns, the upper steam by leaving to that which acts below all its force to elevate the piston, and the lower steam by permitting that which passes into the top of the cylinder to exert, in like manner, all its effort upon the upper part of the piston. Hence it results that the piston is urged with the same force, whether rising or descending; which gives birth to several manifest advantages.

In the first place the counter-weight is suppressed, which is, at least, a surcharge upon the machine: next, the equality of impulsion which obtains in whatever direction the piston is moving, allows it to be applied as a uniform power to a rotatory motion which acts without interruption to produce the proposed effect. Thus instead of the piston's contributing to the principal effect only while it is descending, as in the first machine; in this the piston, whether it be ascending or descending, always acts efficaciously. Supposing that the piston of the first machine has a base double that of the piston of the second, the column of steam which presses upon the base of the former will exert, all other things being equal, a pressure the double of that experienced by the base of the other. But in the two motions of the former, there is only one which is productive; whence it follows that if the second piston, which incessantly labours use-fully, acts upon a double lever, it will perform twice as much as the other could during its descent.

Hence results first a saving in the substance composing the cylinder, and then a corresponding one in all the dependant pieces. Moreover, the capacity and thickness of the boiler may be diminished, because the steam need not be so much accumulated as in the other machines where it issues out only at intervals. Lastly, the surface of the water in the boiler which is yet liquid, being here less compressed by the vapour which is formed above it, that water vaporises in its turn by a less degree of heat; which, joined to the other causes, procures a great economy of combustible.

There may be seen in the Isle of Swans, at Paris, a machine constructed according to the principle which we have just explained, and which is employed to give motion to some corn-mills.

We can only give an outline of the description of this machine, any more than of the preceding. We must far exceed the limits we are obliged to prescribe ourselves, if we undertook to run over all the various accessory parts employed to introduce or to condense the steam, and to exhibit the means which have been adopted to preserve the uniformity of motion, to prevent the accidents which might be occasioned by too strong a condensation, &c. We may, however, observe on this subject, that in the first erected steam-engines, it was necessary to employ men for the especial purpose of turning at every instant the cocks which gave passage to the steam, or to the injection of cold water. At present all is reduced to the attending of that which regulates the fire; the rest proceeds of itself. The force of the steam that animates the body of the machine, is transmitted to the different parts which stand in the place of arms and of hands; and the same genius which has been capable of converting a little water penetrated by heat into an agent that can produce such motions as could require the most powerful efforts, has also attained the art of resting upon that blind cause, even those operations which seemed to demand a vigilant attention and an assiduous care (*p*).

Thus, by comparing the effects of water in its two extreme states, that of solidity and that of elastic fluidity, we see, with a double surprise, the great energy which it displays to break its barriers, either when its moleculæ are given up to the force which acts to enchain them, or when they are shot forth by the force which tends to separate them one from another.

(p) As the succinct account which is here given of the nature of Steam-engines, is not likely to satisfy many readers in this country: those who wish to acquaint themselves more minutely with the principles and manner of operation of this most important class of machines, may be referred to the works mentioned below:—The Repertory of Arts and Manufactures, the Philosophical Journal, and the Philosophical Magazine, in various places; the second volume of Mr. Brewster's edition of Ferguson's Select Lectures, the second volume of Gregory's Mechanics, and the second volume of Prony's treatise entitled Nouvelle Architecture Hydraulique. Tr.

IV. ON THE AIR.

243. After having elucidated the properties of the liquid which bathes the surface of our globe, or glides along within it, we shall proceed to those of the invisible fluid which surrounds it to a great height. Here a very lively self interest is blended with that which the science inspires of itself, to solicit us towards the study of this fluid; in the midst of which we are continually immersed, which acts upon us in so many different ways, and to which we are indebted both for the preservation of life, and for furnishing us with one of its principal delights; since it is to the air that we first commit our thoughts, to be transmitted to others, with the words which are their symbols.

244. It has been remarked, in all times, that the air is always charged by a more or less considerable quantity of heterogeneous principles, of emanations of different kinds, and especially of aqueous vapours. But the air when supposed to be disengaged from all these foreign matters which affect its purity, was regarded as a simple being, and one of the four elements into which all bodies might be resolved by an ultimate analysis. It is now proved, however, that this fluid is constituted of two very different principles, one of which has been named *oxygen gas*, and the other *azotic gas* (*q*). The first, if it existed

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(*q*) The determination of the nature and proportion of the constituent parts of the atmosphere is a delicate problem, respecting which it is reasonable to expect some slight difference in the results. According to the experiments of Mr. Dalton, in a given volume of atmospheric air taken at the surface of the earth, and assumed as unity, the weight of the azote is 0·7555, of the oxygen 0·2332, the aqueous vapour 0·0103, the carbonic acid gas 0·001. He concludes that the proportion of aqueous vapour is variable in different places: it is probable also, he says, that hydrogen is present in the atmosphere, but in too small a proportion to be detected by any experiment we are acquainted with.

Mr. Cavendish is the first who endeavoured to establish that the proportions of the two principal elements of the atmospheric air were constant, notwithstanding the distance of places and the difference of temperatures. The observations since made by M. de Mairy in Spain, M.

alone, would be too respirable, and would consume our life; the second, when we have procured it singly, would suffocate the animals that are immersed in it. From the mixture of the two is formed a fluid perfectly adapted to the functions of the animal economy. The details relative to this object, as well as the manner in which the air is decomposed by respiration, appertains to the science which unveils to us the true nature of this fluid. We shall contemplate it here only in its ordinary state, and we shall refer to four distinct points of view the truths which we propose to develope. The first will shew us the properties which the air most constantly exhibits, such as its heaviness and its elasticity; the second will comprehend those which result from its dilatation by a superabundance of caloric; the third will relate to its union with water, of which it is the dissolvant; the last will have for its object that particular vibratory motion, by the aid of which the air becomes the vehicle of sound.

1. *On the Heaviness and Elasticity of the Air.*

245. Galileo, whose name is presented as of itself, whenever the enquiry relates to the first researches con-

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Berthollet in Egypt and in France, Mr. Davy in England, and by Dr. Beddoes on the air brought from the coast of Guinea, seem to have confirmed this grand result. But one of the finest experiments made on this subject is that of Gay-Lussac in France, who, having been elevated alone in a balloon to the height of 6900 metres, the greatest ever attained by any person, brought some atmospheric air from these regions. This air, being analysed on his return, comparatively with that on the surface of the earth, gave the same principles in the same proportions; a proof that the chemical constitution of the atmosphere at these great heights is the same as at the surface of the earth. This result has been since confirmed by the experiments made by Messrs. Humboldt and Gay-Lussac on eudiometry. The air of the surface of the earth, analysed at different days, at various hours and temperatures, presented no change in its composition: it always contained 0·21 of oxygen in volume, 0·783 of azote, 0·003 of hydrogen, and 0·004 of carbonic acid. Biot and Arrago have also lately verified this grand result. The atmospheric air, analysed in places the most distant from each other, in deep valleys, on high mountains, on banks of lakes, and in the glaciers of Chamouny, always presented to them the same composition. Tr.

cerning gravity, had verified that of the air, which was denied almost universally before him, though it had been discovered by some few philosophers of antiquity. This celebrated philosopher having injected air into a glass vessel, so that it there remained compressed, found that the vessel weighed more than when the contained air was in its natural state. He enquired also, by another experiment, the heaviness of this fluid compared with that of water; but he found it only in the ratio of unity to 400, much too small, as we shall soon see.

246. The pneumatic machine, or air-pump, was not then known. It is to Otto Guericke, a burgo-master of Magdeburg, that we are indebted for the invention of this elegant machine, which is not, like many others, confined to one part of experimental philosophy, for almost all branches derive aid from it.

This machine, when reduced to its greatest simplicity, is composed of a vertical cylinder of brass, in which a piston is moved; its upper base carries a cock, above which is soldered a circular brass plate situated horizontally. On this plate the receiver is placed from which we would exhaust the air, which is executed by making the piston descend and ascend alternately. In the first case the cock is opened in such a manner as to establish a communication between the capacity of the receiver and that of the cylinder; when the piston has descended, the cock is shut, but its key is pierced by an orifice so disposed, that it gives an issue to the air which the piston drives before it when it is elevated, without permitting it to enter again into the receiver. The construction of this machine has been greatly varied: the English have contrived two bodies to the pump, the pistons of which are worked by means of a winch-handle and a rack and wheel; different valves alternately open and intercept the communication between the receiver and the bodies of the pump, and between these latter and the exterior air, so that the cock need only be opened twice, viz.

once before the experiment, to give a passage to the air which should come from the receiver, and again at the end to maintain the vacuum *(r)*.

247. By making use of this instrument, the gravity of the air has been verified by a very simple experiment, which consists in first weighing a ball or bladder full of air, and then weighing it anew after having made the vacuum: a sensible diminution will be perceived in the weight of the ball.

248. Philosophers have attempted likewise to determine, with precision, the specific gravity of the air. According to the results of Deluc, the ratio between the weight of common air and distilled water at the temperature of thawing ice, and under a medium pressure of 29·9 English inches of mercury, is that of 1 to 760; and from the experiments of Lavoisier it follows, that a cubic inch of air, taken at 10 degrees of Reaumur, weighs 0·46005 grains, and that the weight of a cubic foot of the same fluid is one ounce, three drams, and three grains *(s)*.

249. The gravity of the air being once known, it should seem that it could not be difficult to perceive that the ascent of water, in the body of a pump, must be occasioned by the pressure of that fluid. But it needed, to draw thither the attention of philosophers, one of those unexpected observations that are calculated to excite in the mind that species of inquietude and agitation which is favourable to discoveries.

(r) A great variety of air-pumps, of ingenious constructions, have been recently invented in England; for descriptions of which the reader may consult the different performances, except Prony's, mentioned in the preceding note. Tr.

(s) Brisson, as cited by Libes (*Nouveau Dictionnaire de Physique*, I. 31), gives 1 to 810, as the ratio between the weights of common air and water, at the temperature of thawing ice and under the medium atmospheric pressure. The mean between this ratio and that of Deluc, that is to say, the ratio of 1 to $\sqrt{810 \times 760}$, or 1 to 784 nearly, corresponds better than either of them with the ratio usually assigned by English philosophers. For since air expands by about the 485th of its own bulk for each degree of heat upon Fahrenheit's thermometer, and since the difference between

We know that the ancient philosophers, when they were asked why water ascended in pumps, disguised their ignorance by answering that *nature abhorred a vacuum;* which was nothing else than a pompous and imposing manner of acknowledging that they were unacquainted with the matter. Some Italian conduit-makers being asked if they would construct sucking-pumps, whose tubes should be more than 33 feet in height, remarked with surprise that the water refused to rise above that limit. They requested of Galileo the explication of this singular fact; and it is affirmed that that philosopher, being taken unawares, replied that nature did not entertain the horror of a vacuum beyond thirty-three feet. Torricelli, a disciple of Galileo, having meditated upon this phenomenon, conjectured that water is elevated in pumps by the pressure of the exterior air, and that this pressure has only the degree of force necessary to counterbalance the weight of a column of water of 33 feet.

He verified this conjecture by an experiment, for which natural philosophy owes him a double obligation, since it serves to render evident an important discovery, while it has procured us the barometer. Torricelli saw the mercury stand at 28 inches (29·9 English inches) in a glass tube, sealed at its upper part, and situated vertically; and the height thus under consideration being to that of thirty-three feet in the inverse ratio of the densities of water and of mercury, he concluded that the phenomenon belonged to statics, and that it was really, as he had conjectured, the pressure of the air which caused water or mercury to rise until an equilibrium was produced.

This occcurred in 1643. The year following the news of Torricelli's experiment was disseminated in

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55° on Fahrenheit and the temperature of thawing ice is, 55—32 or 23, we shall then have 1 to 784 × $\frac{23}{435}$ of 784, or 1 to 825 nearly, for the ratio of the weights, or of the densities, when the barometer is at 29·9 and Fahrenheit's thermometer at 55°. Tr.

France by a letter written from Italy to father Mersenne. The experiment was performed afresh in 1646, by Mersenne and Pascal; and the latter devised, in 1647, a method of rendering it still more decisive by making it at different altitudes. He invited, in consequence, his friend Perrier to repeat the experiment upon the mountain called Puy-de-Dome, and to observe whether the column of mercury would descend in the tube in proportion as it became more elevated. We may see from the letter of Pascal to Perrier, where he seems to avoid the name of Torricelli, that he had not yet entirely renounced the chimera of the horror at a vacuum which was attributed to nature, and that by admitting that this horror was not invincible, he was not bold enough to assert that it never obtained. The full success of the experiment accomplished the removal of this delusion. Yet this experiment was only a confirmation of that by Torricelli, and therefore yielded an additional ray to the stream of light which issued from it.

250. The pressure of the atmosphere upon a given surface, being nearly the same as would be exerted upon that surface by a column of water of 33 feet high, from this datum has been computed the effect of the pressure under consideration with respect to a man of medium magnitude, and it has been found that it is equivalent to a weight of about 33600 pounds, or 16000 kilogrammes. Such was the weight sustained by those ancient philosophers who seriously denied the gravity of the air.

Considerable as this weight is, its pressure is exerted, so to speak, unknown to us, because it is continually balanced by the re-action of the elastic fluids comprised in the interior cavities of our bodies; and though the air is subject to continual variations, which augment or diminish its density, in consequence of changes of temperature, and of the action of different natural causes, yet as these variations are generally confined within narrow limits, and succeed each other with comparative tardiness, they do not affect us commonly, except in a manner scarcely perceptible. But if there happen a sudden change, as when a man is raised to great heights, the rupture of equilibrium which ensues has a very marked influence upon the animal economy. He then experiences an extreme fatigue, an absolute inability to continue his progress, a drowsiness under which he sinks in spite of himself: the respiration becomes thick and difficult; the pulsations take an accelerated motion*. To explain these effects, it must be considered that the state of well being, in all that depends upon respiration, requires that a determinate quantity of air should pass through the lungs in a given time. If therefore the air that we respire becomes much more rare, the inspirations must of necessity be proportionally more frequent; which will render the respiration more difficult, and will occasion the various symptoms we have spoken of.

With regard to the inconveniences that would result from an air too condensed, man is not exposed to them by the action of natural causes; and it appears that in general they are less than those which are caused by the rarefaction of the air. We need only cite here as a proof of the small magnitude of these inconveniencies, that which happens to divers, when they have been shut up within a bell which descended vertically in the water, and in which the air, pressed by the weight of the surrounding columns, contracts itself more and more, in proportion as the vessel is found at a greater depth. The accidents which have occurred to those who have continued for a certain time under the bell, have arisen in great part from the alteration produced in the air by respiration, and that which

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* Saussure, Voyage dans les Alpes, Nos. 559 and 2021.

was most dangerous in this fluid was the defect of renewing it (t).

On the Barometer.

251. The details relative to the construction of the barometer naturally claim a place here. This instrument, reduced to its greatest simplicity, consists of a glass tube of more than thirty (thirty-two English) inches high, and hermetically sealed at top. This tube is filled with mercury, which has been carefully boiled, to purge it of air; afterwards, holding the finger applied to the inferior orifice, the tube is reversed, and that end plunged into a little glass cup, wherein mercury has likewise been poured. The finger being withdrawn, we shall immediately see the mercury descend in the tube to the height of about 28 (29·9 English) inches: then this tube, with its little basin, is applied to a plate divided into inches and lines, reckoned from the upper surface of the mercury

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(t) Dr. Hutton (*Math. and Phil. Dictionary*, I. 166) has often heard the late unfortunate Mr. Spalding relate his method of descending with the diving-bell. He always found it absolutely necessary to descend with the bell very slowly, first for about 5 or 6 fathoms, and then to stop awhile: for he felt an uneasiness in his head and ears, which increased more and more as he descended, till he was obliged to stop at the depth above mentioned, where the density of the air in the bell was nearly doubled. Having remained there awhile, he felt his ears give a sudden crack, after which he was soon relieved from any uneasiness in that part, and it seemed to him as though the density of the air was not altered. He then descended other 5 or 6 fathoms, with the same precaution and the same sensations as before, being again relieved in a similar manner, after remaining awhile at the next stage of his descent, where the density of the air was tripled. And thus he proceeded to a great depth, always with the same circumstances, repeated at every five or six fathoms, and adding a pressure equivalent to that of the atmosphere at every new augmentation of the descent. Tr.

contained in the basin. Thus have we a means of observing the variations in the pressure of the air, occasioned by causes on which the phenomena of meteorology depend.

252. This construction is liable to an imperfection, which prevents the motions of the column of mercury, estimated according to the indications of the scale, from being exactly proportional to the different pressures of the air: for, as that column rises or descends, it causes a small portion of the mercury contained in the cistern or basin to pass into the tube or to re-enter into that basin, which varies the position of the upper surface of its contained liquid; so that it does not constantly correspond to the zero of the scale, which is, notwithstanding, the term of departure to which is referred the observation of the height agreeing with the extremity of the column upon the same scale. This imperfection is so much the less perceptible, as the basin has more breadth about the place of the line of level. Different methods have been contrived to make this disappear: for example, in certain barometers the scale is rendered moveable in the direction of its height; in such manner that, with the aid of a micrometer screw, one can always bring the line of level to stand exactly opposite the zero of the scale. In such case there is substituted for the basin a portion of the tube of the instrument, which is here turned up again, at its inferior part, the sensible variation of the level which results may always be corrected by the motion of the scale. Other philosophers have employed a second cistern of a greater capacity, and partly filled with mercury in which the basin of the barometer is entirely immersed. When an observation is to be made, the barometer, with its basin, is elevated above the surrounding mercury; and then, as that basin is always found full, the line of the level given

by the upper surface of the mercury which it contains, retains a fixed position with respect to the graduation *(u)*.

253. It is manifest from the preceding remarks that the scale of the barometer is regulated by a principle completely distinct from that of the thermometer. The motions of the liquor in the latter instrument are measured in parts proportional to the distance between the two limits given by observation; they differ in different thermometers, though by similar degrees when the circumstances are the same: in the barometer, on the contrary, where there is only one fixed term,

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(*u*) M. Pugh, in his *Observations sur la Pesanteur de l'Atmosphere*, &c. published at Rouen, directs that to remedy the inconveniences attendant upon the upright barometers, a graduated ruler should be applied parallel to the tube having its lower end floating on the surface of the mercury, in the cistern, according to the motion of which the scale will ascend or descend. Two or three supports, through which the ruler may pass so as to move freely, will be sufficient to keep it parallel to the column of mercury, whose length will be always visible; but for greater exactness a moveable index with a vernier may be adapted to the scale, in such a manner that one end shall be on a level with the surface of the mercury in the tube while the vernier indicates the exact measure of the column.

Wheel-barometers may also be constructed to avoid most of the defects hitherto thought unavoidable in such instruments, thus: Let a solid piece of glass, in the form of a pear, float upon the surface of the mercury in the tube: to the bottom of this ball let a piece of thread be attached, which may descend quite through the column of mercury, and pass round a pulley placed under the orifice of the tube, from whence let it proceed to a second pulley, placed parallel to the former in the cistern, and afterwards over the pulley in the centre, which gives motion to the index: at the extremity of this thread must be fixed another small solid ball of glass to give motion to the index when the mercury descends.

On account of the two pulleys it will be necessary to make the cistern of such a size, that if the column of mercury should experience the whole extent of the variation, the height of the mercury in the cistern may suffer no visible change: thus, suppose that the diameter of the cistern is 4 inches, the total variation of the column will occasion a difference of $\frac{1}{24}$th part of an inch in the height of the mercury in the cistern, which is equivalent to an angle of 5 degrees formed by the index; but if the diameter of the cistern be 6 inches instead of 4, the difference will not exceed $\frac{1}{48}$th of an inch, corresponding to an angle of $2\frac{1}{2}$ degrees. Tr.

namely, the level of the mercury in the cistern which is established of itself at the first instant, the height of the column is measured in an absolute manner; and it increases or diminishes by equal degrees, in the different barometers subjected to the same variations of the atmosphere.

If we would introduce the decimal division into the barometer scale, the limits of the variations of whose column extend over the space comprised between 26 and 29 French inches nearly; they correspond, the one to 70, and the other to 78 centimetres, from the line of level, which makes 8 centimetres for the field of observation; in the same case, the mean height of 28 inches will answer to 758 millimetres.

On the Elasticity of the Air.

254. The elasticity of the air, in considering which we shall now be occupied, is verified by several well-known experiments. One of the most ordinary is that in which we employ the machine called the *fountain of compression.* It consists of a metallic vessel of a rounded form, its summit being pierced with an orifice, through which the vessel may be filled with water to about the two-thirds of its capacity. In this aperture a tube is then fixed, which descends into the vessel until it is within a little distance of the bottom, while its upper part, which projects from the orifice, is furnished with a cock. To this same part a forcing pump is adapted, and the cock being opened, a great quantity of air is injected into the vessel: this air, being lighter than the water, rises above it, and its elasticity augments with its density, in proportion as new strokes are given to the piston. Then, after closing the cock, the pump is removed, and a kind of little hollow cone is substituted for it, open at its sum-

mit, which is turned upwards: as soon as the cock is again opened, the condensed air exerts its force upon the surface of the water, and drives it through the canal that is immersed into that liquid, whence it is seen to shoot out, under the form of a jet of above ten metres (more than 30 feet) in height.

255. An analogous effect may be obtained, solely by the slackening of the natural elasticity of the air, by placing under the receiver of an air-pump a little vessel, in which all is similar to what the fountain of compression presents, at the moment when the cock is opened to give a free passage to the water, except that the air situated above this liquid is in its ordinary state. While the exhaustion is going on, the air included in the vessel, and whose pressure upon the water is no longer balanced by that of the exterior air, dilates itself, and gives birth to a jet which rises under the receiver.

256. But the most interesting experiment relative to this object is that of Boyle and of Mariotte, to shew that the air contracts itself nearly in the ratio of the weights with which it is pressed. These kinds of experiments merit the preference, since they are not confined to merely proving the existence of a phenomenon, but make known also how it exists, by determining the law to which it is subjected.

Let us take a glass tube, bent into two branches, the shortest of which is adout 32 centimetres or 12 inches high; it must be equally thick throughout, and hermetically sealed at its extremity. The other branch, which is open, should be at least 26 decimetres, or eight feet in height. The whole is fixed upon a plate which carries a division adapted to the two tubes. First, let there be poured into the bent part a little mercury, to obtain a line of level, that we may estimate the number of degrees comprised between that line and the superior extremity of the shortest branch. In this state of things the air which occupies that branch maintains an equilibrium by its elasticity, with the pressure of the column of atmospheric air gravitating in the other branch, and whose pressure is transmitted by means of the mercury comprised in the inferior curvature. This pressure, as we have seen (251) is equal to that of a mercurial column of about 76 centimetres, or 29·9 English inches in height. Afterwards, let mercury be poured into the longest branch, and at the same time the air in the other branch will be condensed; by the excess of the resulting pressure the mercury will rise in the shorter branch until an equilibrium is again produced. Then measure, on one part, the length of that column of compressed air, and on the other the excess of the column of mercury contained in the longest branch, above that which occupies the shortest. We will suppose, for more simplicity, that this excess is equal to 76 centimetres; in that case, we shall find that the column of compressed air is reduced to the half of the height which it occupied previous to the introduction of the fresh mercury. But that column is charged with a weight double of the former, since a pressure of 76 centimetres of mercury is added to an equal pressure exerted by the atmospheric air, and which is not considered as being diminished; for we may neglect the small difference which results from this, that the 76 centimetres which terminate the atmospheric column at bottom are actually occupied by the mercury. In general, if we take the ratio between the first pressure due to the column of the atmosphere, and any other pressure whatever exerted by that same column and by the mercury superadded, the corresponding spaces, occupied by the compressed air, will be respectively in the inverse ratio of the pressures; whence it is obvious that the air contracts itself, as we have stated, in proportion to the weights compressing it. If we afterwards take out the mercury at several distinct times, the air will expand by reason of its elasticity, and the spaces which it will successively occupy in a contrary order will still conform to the inverse ratio of the pressures.

Nevertheless, it is probable that this ratio is only sensibly exact between certain limits, even when it is supposed that the air submitted to the experiment is dry and continues always at the same temperature, a necessary condition. We may find in writers on physics many results of experiments which would tend to prove that they have pushed the contraction and dilatation of the air very far, by the augmentation or the diminution of pressure; but it does not appear that much can be said as to the precision of those results *(v)*.

(v) M. Haüy might have spoken with less hesitation on this topic; for it is now well known that the *Boylean law* is limited to small compressions. Sulzer compressed air into $\frac{1}{2}$ of its former dimensions, and shewed clearly that the elasticities do not increase so fast as the densities. Other experiments for the same purpose were instituted by the late professor Robison, who also proved that, in dry air, the elasticities do not increase so rapidly as the densities, the differences being indeed rather greater than those given by Sulzer. He also made experiments on damp air in a warm summer's morning: in these it appears that the elasticities are almost precisely proportional to the densities + a small constant quantity, deviating from this rule chiefly between the densities 1 and 1·5. When air was strongly impregnated with vapours of camphire, the experiments were tolerably conformable to the Boylean law: or rather, the elasticity seemed to increase a *little* faster than the density. Tr.

Various Phenomena produced by the Gravity and Elasticity of the Air.

257. If we suppose, for an instant, that the air of the atmosphere has the same density throughout, and that we afterwards pay attention to the effect of gravity on the different strata of this elastic fluid, it is easy to conceive that each stratum or bed being compressed by the weight of the superincumbent ones, will be contracted in the direction of its height, and that, moreover, the densities of these strata will diminish in proportion as being at a greater distance from the surface of the earth they would be pressed by a smaller number of superior layers. This is what obtains effectively with regard to the atmosphere. We shall shew, in the sequel, the law of this diminution, and the method which has been deduced from it for measuring altitudes by means of the barometer.

258. We may conceive, in like manner, that any part whatever of a column of the atmosphere, taken at the surface of the earth, must always maintain an equilibrium by its elasticity with the pressure of the superior part. Thus the air exactly contained in a cup which has been deposited in an inverted situation, on a perfectly even plane, will make just as great an effort to thrust the bottom of the vessel upwards, as the exterior air to push it in a contrary direction; so that no difficulty would be experienced in removing this vessel, which indeed is conformable to observation.

But if a more or less considerable quantity of the interior air be suppressed, as is the case, in fact, when a vacuum is made under the receiver of an air-pump, then the pressure of the exterior air being no longer balanced by the contrary action of that which remains under the receiver, there will result a difficulty in detaching this receiver from the plate, which will be so much the greater as the vacuum approaches nearer to being perfect.

259. It follows again from the principles previously established, that if there be taken at the surface of the earth a certain quantity of air whose spring will of consequence maintain an equilibrium with a pressure of about 76 centimetres (30 English inches) of mercury, and that air be let into a void space where it may dilate itself; its elastic force, diminished by the dilatation, will be to the primitive force, in the inverse ratio of the volumes or of the spaces relative to the two successive states of the fluid. This may be verified by the aid of an interesting experiment, which consists in introducing into a common barometer a determinate quantity of air, employing for the measure a tube of the same diameter as that of the barometer, and whose height is known. That air having reached the top of the column of mercury, will expand by its elasticity, in the void space it there meets with, and will cause the mercury to be depressed, until the elastic force of the air joined to the weight of the mercury remaining in the tube, will be in equilibrio with the pressure of the atmosphere. We may determine beforehand, by a simple computation, the height of the space into which the air must expand itself, or, which comes to the same, the height at which the column of mercury must stand. For example, if the tube be 90 centimetres in height, and there be introduced 8·25 centimetres of air; it will be found, on the supposition that the pressure of the atmospheric air to which the mercury was at first subjected was of 76 centimetres, that this liquid will descend to 57 centimetres above the level in the cistern; so that the space occupied by the air will be 33 centimetres*.

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* Let, in general, h be the height of the tube commencing at the line of level in the basin, p the pressure of the atmosphere, as measured by the barometer, n the quantity of air, or the part of the tube's length which it would occupy if it retained its primitive density, and let x be the height at which the mercury will stand after the dilatation of the air; then $h-x$ will be the part of the height of the tube into which the air will diffuse

260. This conducts us to the explication of the effects produced by the fountain to which the name of *intermitting* fountain has been given, and of which this is the construction. A B C (fig. 26. pl. IV.) is a globe of glass or of any other substance, pierced with several holes, to which are adapted the little tubes *n*, *o*, *r*, *s*, and traversed in the direction of its vertical axis by a tube C Z, whose upper part *i* is raised to within a small distance of the summit *o*, and whose lower part is fitted exactly into the hollow cylinder S D, fixed at the bottom of a cistern M T. The lower part of this cylinder is hollowed laterally at *u*, so that there is a free communication between the air contained in the vessel A B C, and the exterior air. The cistern M T is pierced with a little hole, by means of

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itself by expanding. Now the spaces occupied by the air in its two states being in the inverse ratio of the densities, we shall have $h\text{-}x : n :: p : \frac{n p}{h\text{-}x}$, which will express the density or the force of the dilated air. But this latter quantity, augmented by x which expresses the height, and at the same time the force of the mercury, must be in equilibrio with the pressure of the atmosphere. Therefore $\frac{n p}{h\text{-}x} + x = p$, whence we deduce $x^2 - (h+p)\,x = n p - h p$, and $x = \frac{h+p}{2} \pm \frac{1}{2}\sqrt{4np+(h-p)^2}$.

If we make $h = 90$ cent., $n = 8{\cdot}25$ cent., as above, we shall find $x = 57$, and $x = 109$. The first value belongs to the present supposition, and gives $76 - 57$ or 19 centimetres, for the expression of the force of the dilated air. The second value relates to another problem, in which it is supposed that there is a tube closed at bottom, open at top, and of a height equal to h. There is supposed, moreover, at the bottom of the tube a column of mercury, whose height, or, which amounts to the same, whose pressure, was equal to p; then above this a column of air which, under the pressure of the atmosphere, would occupy the space n; and finally, above this latter, a new column of mercury which filled the rest of the tube. This tube is considered as placed under an exhausted receiver: the air included in the tube will then dilate itself, expelling a portion of the mercurial column which presses upon it, until its elastic force is in equilibrio with the remainder of that superincumbent column. In this case the quantity x which it is required to determine will be the distance between the bottom of the tube and that of the superior column of mercury after the dilatation of the air.

which it communicates with a reservoir K placed below it. When we would make use of this fountain, we must take the tube C Z from the cylinder S D, and then invert it in order to pour through it water into the vessel A B C, until the latter is full. The tube is then to be turned again, and replaced in the cylinder S D: at this moment the exterior air which enters freely by the cavity *u*, will exert its pressure upon the surface *ab* of the liquid: it will also act with a force, equal as to sense, upon the water which tends to spout forth from the tubes *n*, *o*, *r*, *s*, in such manner that in this respect the water is in equilibrium between the two forces of the air. It will therefore flow from the little tubes in virtue of its proper weight. In proportion as this water falls into the cistern M T, a part will pass through the hole with which its bottom is pierced; but as it receives more than it thus loses, there will be a term when the cavity *u* will be so stopped up with water that the air can no longer enter into the vessel ABC. Nevertheless the water will continue to run out for a short interval, while the interior air dilates itself, and its spring becomes so weakened that this force together with the weight of the water are in equilibrio with the pressure of the air at the orifices of the tubes *n*, *o*, *r*, *s*; then will the discharge which is made by these tubes stop at once. But the cistern M T continuing to empty itself, it will soon happen that the cavity *u* becomes again open, and that the air is again introduced into the vessel A B C, so that the little tubes will recommence their delivery of water. The fountain will thus flow and cease alternately, until the vessel which furnishes the water is emptied.

On Pumps.

261. We might limit ourselves to pointing out, generally, the air as the cause of the elevation of water

in the body of a pump. But the manner in which the exterior pressure of this fluid is combined with another action, which it exerts within and which depends on its elasticity, is susceptible of some details, the more worthy of our attention, as they tend to make known one of the most elegant and useful productions of mechanics.

All pumps may be reduced to three kinds; namely, the *lifting pump*, the *sucking pump*, and the *forcing pump*, called by the French *foulante and aspirante*, because it combines the effects of the two former.

262. The lifting pump has its piston placed below the level of the water. It is constructed in two different ways: in the first, the rod *t* (fig. 27. Pl. IV.) of the piston P is situated beneath it, and the piston is pierced with a vertical cavity, whose upper aperture is furnished with a valve *s* turning on a joint. When the piston is at rest, it occupies the bottom of the body of the pump, within which the water is introduced of itself, through the piston, whose valve it raises up, by its tendency to find its level. Near the place *m n* of this level the body of the pump, likewise, is furnished with another such valve *s'*, which performs the office of a second bottom moveable upwards; this is sometimes called the sleeping valve. While the piston is elevated by means of a motion communicated to the rod, the valve *s* becomes shut, and the water with which it is loaded rises with it till it reaches the sleeping valve *s'*, which is forced open to give a passage to that water: then the same valve shuts again by its weight, and prevents the liquid from running out. The piston acquires by descending a new load of water with which it remounts, to deposit it at the same place as the former; so that the water may thus be elevated to an arbitrary height, provided the mover has a sufficient force.

263. The pumps of the second construction differ from the preceding, by the position of the rod, which is situ-

ated above the piston; a farther difference consists in the circumstance that the piston is solid (or without any cavity), and rests upon a valve with which the bottom of the pump is furnished. When the piston is raised the water follows it to gain its level; during its descent it forces this water into a lateral tube, wherein it opens a passage by lifting up a sucker, which falls again as soon as the piston has arrived at the bottom of its course.

264. The sucking pump represented fig. 28, has its piston P elevated above the upper surface, or level, *m n* of the water, to a height which should always be less than 33 feet. This piston is hollow, and furnished with a valve *s* at its upper part. The body of the pump has a separation formed by another valve *s'* at a certain distance below the point *k*, where we conceive the stroke of the piston to be terminated downwards. When the piston is at rest in that position, the interior air comprised between the sleeping valve *s'* and the level *m n* of the water makes an equilibrium by its elasticity with the pressure of the exterior air. As to the air included in the space *klzo*, above the sleeping sucker, and whose elasticity is sensibly equal to that of the inferior air, its effect is limited, for the moment, to the keeping that sucker closed. Afterwards when the piston rises, the air contained in the space *k l z o* becomes dilated, that which is underneath the sleeping valve rises by reason of its excess of elasticity, and a part of it diffuses itself throughout the space *k l z o*. At the same time the water rises till it reaches the term where the elasticity of the air, enfeebled by its dilatation, joined to the weight of the water which has risen beyond the level *m n*, makes a sum equal to the pressure of the atmosphere upon an equal base. This situation of things obtaining at the moment when the piston ceases to rise, the sleeping valve being then between two volumes of air equally dilated, closes itself again by its own weight. The piston by descending compresses the volume of air included between its base and the sleeping valve; and as

the volume of that air exceeds the primitive volume by a quantity equal to that which has entered the space *k l z o*, it is evident that there is a point where it will become denser than in its first state, and then it will lift up, by its elasticity, the valve *s* placed upon the piston, and a part of the water will continue to escape, until the remaining air has resumed its natural density. While the ascending and descending motions of the piston are repeating, the water continuing to mount arrives at the piston, which each time of being depressed, forces the liquid to pass through its orifice to be afterwards raised with it; and so on successively until it is conveyed to the desired height.

The construction of this species of pump requires certain precautions, to obviate an inconvenience which, at first view, appears singular. It is possible that the water before it reaches the piston should stop all at once, and refuse to mount farther, although the reciprocating motion of the piston continues. To comprehend the possibility of this, we must remark that the weight of the water reckoning from the surface of that in the reservoir, augments continually in proportion as it rises, while the quantity of air which remains between the water and the base of the piston, and whose elasticity shews itself the more as the latter continues to rise, proceeds on the contrary diminishing. Hence it results that the relation between the two forces which together react against the pressure of the atmosphere, varies continually; and thus it may happen that the sum of these forces may at a certain term become capable of opposing to that pressure a greater resistance than it had done previously. Let us suppose, for example, that the water has arrived at *h r*, and that it is there retained by any power whatever, while the piston is raised from *k l* to *f g*, which is the limit of its motion. If the space *h r g f* left void by the upward motion be such that the elasticity of the air after its dilatation, joined to the weight of the water which is above the level, are in equilibrio with the pressure of the atmosphere, it is easy to see that the water would not rise farther, even if it were not retained by an extraneous force; since the condition requisite for the equilibrium is fulfilled by the dilatation of the air alone.

If therefore the pump be so constructed that thére is a point where the hypothesis which we have been laying down may be realised, the water will remain stationary at that point. To prevent this hypothesis from being ever admissible, and to cause the pump to render its service in every case, it is necessary that there should be between the stroke of the piston and its greatest altitude above the level, a certain relation which may be determined with facility by means of calculation *(*w*).

265. The water is raised in the forcing pump, on the same principle as in the sucking pump. But here the piston is solid (without any perforation), and when the water has arrived at its base, it pushes it back as itself is depressed, and forces it to pass into a lateral tube in such manner as obtains with respect to the second kind of lifting pump, of which we have spoken.

This pump only differs from the preceding in the circumstance that the water, instead of passing through the piston during its depression, is driven into an appropriate tube; so that this effect of the piston is considered as being more marked, and seems to be more characteristic of the action of forcing.

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* The rule to which the computation leads, is, that the square of the half of the greatest height of the piston above the surface of the water, or of the distance between *fg* and *m n*, must be less than 33 times the stroke of the piston, which is measured by the distance between *fg* and *k l*.

(*w*) When the sucking pipe is of a smaller diameter than the body of the pump, if the condition above stated obtain, the pump cannot fail to produce the proper effect: for the air is dilated with more facility in this latter case than when the whole is of the same internal diameter. But if the length of the stroke in a uniform pump, which is requisite to render the machine effectual, be greater than can conveniently be made, it may be diminished by contracting the diameter of the sucking pipe in the subduplicate ratio of the diminution in the length of the stroke. Tr.

The Syphon.

266. It is also to the pressure of the air that we must ascribe the effects of the syphon, which serves to transfer liquors from one vessel to another. This name is given to a tube of glass or of metal, bent into two branches one of which is longer than the other. This instrument must be so held that the bent part shall turn its convexity upwards. The shortest branch is plunged into the vessel which contains the liquor; and the mouth being applied to the orifice of the longest branch, the liquor is drawn by sucking, that is to say, the lungs are inflated, by which means a dilatation is produced in the air occupying the interior of the syphon; and immediately the air is introduced into the latter by the pressure of the exterior air. When the syphon is full, the mouth *(x)* is taken away, and the liquor continues to discharge itself at the extremity of the longer branch until the vessel is empty.

The reason of this effect may be easily understood, if we consider that the air which corresponds to the orifice of the longest branch presses upwards, according to the law of all fluids, the column of water contained in that branch, while the air which is sustained by the surface of the liquid contained in the vessel, acts by the intervention of that liquid so as to press in the same direction the column occupying the shortest branch; and it is evident that it will have no need to sustain more than the part of that column which is elevated above the surface of the liquid in the vessel. Now, the difference between this same

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(x) The operation of sucking out the liquor at the orifice of the longest branch, which is often both disagreeable and troublesome, may be prevented by having an aperture at the top through which the syphon may be completely filled, and then that aperture closed again. Or if the syphon be small it may be inverted and filled with the liquid, which may be kept in by a finger applied at each end, until it is placed at the proper position for work, when the fingers may be removed. Tr.

part and the column included in the longest branch, gives to the latter an excess of weight which is not, in any perceptible degree, balanced by the excess in the length of the column of air which answers to the same branch; and hence all that portion of the liquor which is not sustained by the air will fall; and as it is incessantly replaced by that which proceeds from the vessel, the discharge can only terminate when the liquor is exhausted, or at least when it has sunk below the shorter branch of the syphon.

267. A multitude of facts have been long known which have been usually attributed to the horror of nature for a vacuum, yet whose explication is presented as of itself, after the details into which we have entered relative to the heaviness and elasticity of the air. When we attempt to draw back the piston of a syringe whose orifice is stopped up, we experience a strong resistance, as though the piston were attached to the bottom by a certain power, while in fact it is the weight of the air, which by pressing upon the superior part of that piston hinders its rising. For the same reason we separate with difficulty the pannels of a pair of bellows, whose flap or valve and pipe are closed. When we place between the lips a tube whose lower part is immersed in water, and suck up the interior air to produce the ascent of the liquid, the suction appears to be a force which acts by attraction, while it is nothing else than rendering preponderant the action of the exterior air, and thus causing the elevation of the water in the tube. We might adduce many other effects of a similar kind, whose appearances are as delusions held forth to the imagination.

On the Measure of Heights by the Barometer.

After having shewn in what manner the discovery of the pressure exerted by the air upon other bodies has contributed to the perfecting the theory of that fluid, it remains for us to shew an application of this discovery, which has doubled the advantages of the barometer.

The experiments of Torricelli presented this instrument to Natural Philosophy, to facilitate and give accuracy to the daily observations relative to the state of the air: those of Pascal gave birth to the idea of substituting it, in certain circumstances, for the geometrical means employed for the measure of heights.

268. The most simple method of applying the barometer to this use, is founded upon an observation which can only be regarded as a first glimpse. It consists in supposing that in general one line ($\frac{1}{12}$ part of an inch) of diminution in the mercurial column answers to a difference of twelve toises and a half in the vertical altitude. This result expressed in the language of the new French measures, gives 108 decimetres of elevation for each millimetre that the mercury is depressed. The employment of this method ought to be limited to heights not very considerable, such, for instance, as do not exceed a thousand or twelve hundred toises above the surface of the sea(*y*).

269. The law according to which the densities of the air decrease, has furnished another method approaching much nearer to precision, and extending to all altitudes to which we can attain. Proceeding from the principle given by observation that the air is compressed in the ratio of the weights with which it is charged, it is proved that when the heights are in arithmetical progression, the corresponding densities are in geometrical progression; and it is manifest that these densities are in their turn proportional to the depressions of the mercury in the barometrical tube.

(*y*) The application of this rule ought rather to be limited to altitudes of about one-tenth the magnitude our author speaks of. If so simple a rule would give accurate results to altitudes of 1200 toises, there would be, comparatively, very few cases in which any other rule would be necessary. TR.

270. This relation between the heights and the densities of the air corresponding to them may be demonstrated very simply. Let *a b z s* (fig. 29) be a slice of air taken between the surface *a b* of the earth and the limit *s z* of the atmosphere. Suppose this slice or trench divided into an infinitude of others of a thickness infinitely small, by the parallels *d c*, *e f*, *g h*, &c. to the line *a b*, whose distances *a d*, *d e*, *e g*, &c., are respectively equal: it is evident that the densities of these different slices continually diminish from the line *a b*, and that, moreover, they are successively as the weights of the quantities of air situated above each of them, in such manner, for example, that the density of the slice *a b c d* will be to that of the following *d c f e*, as the weight of the air contained in *d c z s* is to that of the air contained in *e f z s*.

Conceive now a curve *b p x s* to be so traced that if the air contained in each space *a b c d*, *d c f e*, &c., were reduced till it only occupied the corresponding space *a b n d*, *d n o e*, &c., taken in the interior of the curve, the fluid would be found uniformly distributed in the total space terminated by that curve. It is easy to conceive how this hypothesis may obtain; because the primitive densities of the air and the spaces *a b n d*, *d n o e*, &c., situated in the interior of the curve, being both in a diminishing progression, we have the power of choosing such a curve, that the portions of air supposed to pass from the spaces *b n c*, *n c f o*, &c., into the contiguous spaces, *a b n d*, *d n o e*, &c., shall augment the densities of the air which previously occupied these latter spaces, so that their differences shall vanish.

This granted, it is obvious that the spaces *a b n d*, *d n o e*, &c., being so much the smaller as the primitive densities themselves are smaller, their ratio will be the same as that of those densities; farther, the spaces *d n s*, *e o s*, &c., situated above the former, will be in succession as the weights of the quantities of air which compress that included in the spaces *a b n d*, *d n o e*, &c. And since the air is condensed in the ratio of the weights with which it is charged, it results that the spaces dns, eos, &c., will be also proportional to the spaces $abnd$, $dnoe$, &c. Now these latter are the differences between the former, and it is demonstrable that when quantities are respectively as their differences, those quantities, and consequently their differences, are in geometrical progression*; therefore the spaces $abnd$, $dnoe$, $eopg$, &c., or, which amounts to the same, the densities of the air corresponding to the altitudes ad, ae, ag, &c. conform to the law of a geometrical progression; and since these altitudes are evidently in an arithmetical progression, because of the equality of the distances ad, de, eg, &c., we hence conclude that when the heights form an arithmetical progression, the corresponding densities of the air are in a geometrical progression.

But, the elevations of the mercury in the barometer are proportional to the densities of the air that correspond to the different heights where those mercurial elevations have place. If, therefore, on one part these densities are expressed by the numbers of the lines (twelfths of inches) which measure them, commencing at the surface of mercury in the barometer basin, and if, on the other hand, the heights corresponding to the elevations of the mercury are represented in toises, we may consider the numbers of toises as the logarithms of the numbers of lines.

Let it be supposed, for a moment, that there is a table constructed according to this system of logarithms: it is easy to see how we might by its means ascertain the height of a mountain. We should take the two numbers of lines indicated by the barometer at the highest and

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* Let $abs = a$, $dns = b$, $eos = c$, $gps = d$, &c.; we shall have, by hypothesis, $b : a - b :: c : b - c :: d : c - d$, &c. Therefore, $ac - bc = b^2 - bc$, and $bd - cd = c^2 - cd$; whence we draw $ac = b^2$, and $bd = c^2$. Consequently $a : b :: b : c$, and $b : c :: c : d$; that is to say, the quantities a, b, c, d, &c. are in geometrical progression: whence it follows, that the differences $a - b$, $b - c$, $c - d$, &c, form also a geometrical progression.

lowest points of the altitude to be measured, should seek in the column of logarithms the corresponding numbers of toises, and the difference between those two numbers would give the vertical distance between the two stations, or the height required.

271. Now various philosophers have thought that such a labour as this might be dispensed with, and the common logarithms be made to serve for the determination of altitudes by the barometer. To accomplish this, it was only necessary to obtain a constant factor of such value that its product, by the logarithms of our tables, should furnish measures conformable to the observations. The first determinations of this kind were founded on observation itself; that is to say, after having chosen among the results of several trigonometrical operations those which appeared to merit the most confidence, the value of the factor was sought which ought to be introduced into the computation relative to the indications of the barometer, so that the results of that calculus should accord with those of which trigonometry had furnished the data. Deluc, by following this process, has been conducted to a determination of a happy simplicity, since it left scarcely any thing to do, to reduce to the numbers which this philosopher considered as true those given by the common tables: it consisted in this, that the logarithms of these tables, taken with seven decimals, need only be multiplied by 10000, to represent in toises the true logarithms of the number of lines which measured the corresponding observations of the barometer. Hence, after having taken the difference between the two tabular logarithms of the number of lines in question, remove four places towards the right the virgule or point following the characteristic of the logarithm, so will there be expressed in toises and decimal parts the vertical distance between the two stations.

272. This result, however, and all others of the same kind, require several corrections, two of which especially have fixed the attention of philosophers. It is known

that the temperature varies in the different points of the same column of air, in such manner that the superior strata are generally colder than the inferior ones. Now the densities of the air corresponding to vertical heights in arithmetical progression, are only considered to be exactly in geometrical progression, so long as the temperature of the air is uniform: whence it is manifest that, in ordinary cases where the temperature varies, it is necessary to correct the heights of the barometer. But on another part the inequality of temperature has immediate influence, by a thermometrical effect, upon the column of mercury included in the barometer, and producing there an augmentation or a diminution of length, which is foreign to the indications of the instrument, and therefore requires a new correction.

273. Different methods have been devised to cause the disappearance of these anomalies. Those who proceed after the method of Deluc, first suppress the effect which is caused by the immediate influence of temperature upon the barometer, and refer the indications of the instrument to those which would have taken place in the case of a variation due to the pressure of the atmosphere alone. They then ascertain the number of toises which exhibit the elevation proposed, estimating from the corrected heights of the barometer; and afterwards apply to this same number the correction depending on the variable action of heat upon the column of air comprised between the two stations.

To determine the first correction, Deluc enquired experimentally, at what degree of temperature the height of the barometer required no correction. This degree answered to the tenth above zero, upon the thermometer of 80 parts. Deluc also deduced from experiment the quantity by which the variation of temperature lengthened or shortened the barometrical column, for each degree of the thermometer. This quantity was 0·075 of a line, supposing that the barometer had been at first at 27 French inches. In the case of a different height, a certain reduction gave the quantity of the variation. It was afterwards easy to add to the observed height that which it was deficient, or to retrench that which it was too much, in proportion as the temperature differed from that of 10 degrees, which served as a fixed point.

With regard to the other correction, Deluc enquired in like manner at what temperature there was not any change to make in the number of toises given by the logarithms of the heights modified according to the first correction. This temperature was of 16¾° above zero. He then supposed that the temperature varied, through the extent of the same column of air, so as to increase or decrease in arithmetical progression; and it resulted from his experiments that the air augmented or diminished by $\frac{1}{215}$ of its volume, for each degree of the thermometer of 80 parts. By combining these data with the observations of temperature in the two stations, the error in excess or defect of the number of degrees obtained by the aid of logarithms is determined.

274. Laplace has proposed a method furnishing more direct means of arriving at the same object, and leaving nothing to desire, when the determination of the quantities which serve as its bases has been taken afresh, with all the precision of which it is susceptible.

In this method the constant coefficient by which the number given by the tabular logarithms must be multiplied, depends upon the ratio between the weight of a determinate volume of mercury and that of an equal volume of air, at the temperature of thawing ice, and at the mean height of the barometer at the surface of the sea. This height is very nearly 76 centimetres (28 French or 29·9 English inches), and the specific gravity of the air compared with that of the mercury, such as are indicated by the experiments hitherto made, is in the ratio of 1 to 10283. From these data the constant coefficient of the difference between the logarithms of the numbers of centimetres that measure the elevations of the barometer at the two stations, is equal to 17972·1 metres.

275. Now the hypothesis of a uniform temperature equal to zero requires in like manner two corrections, before it will conform to the indications offered by the thermometer during the same operation. The first rests upon the constant coefficient: the better to understand in what it consists, let us suppose that the temperature, at the lowest station, is, for example, 16° above zero, and that at the highest station it is 4° above the same limit. The heat being considered as decreasing in arithmetical progression in proportion as [illegible] temperature is depressed, its effects upon the air comprised between the two stations will be such that the differences between the real densities of the different beds or strata of that air estimated by ascending, and those which would obtain in virtue of the pressures alone, would themselves follow an arithmetical progression.

We may therefore consider the whole operation as performed at a uniform temperature of 10°, which being the half sum of the extreme temperatures, gives the mean term of the progression. Thus the effect will be the same as if the temperature having been at first at zero, was suddenly elevated to 10° through all the mass of air comprised between the two stations. But, in this hypothesis, the dilatation undergone by the air would have caused the different strata of air to rise above their first level; whence it follows, that the column of mercury in the barometer, as the observer raises himself, being pressed by a greater quantity of air than if the temperature were zero, the barometer will descend less than in the case of that same temperature; and consequently the calculus if made without any correction would give a defective result. To compensate this error, therefore, it is necessary to augment the constant coefficient by a certain quantity which must be determined. Now, we have observed that, at the temperature of melting ice, the air is dilated by about $\frac{1}{250}$ of its volume for each degree of the centigrade thermometer, which is the thermometer made use of in operations of this kind. Consequently the quantity whereby it is necessary to augment the constant coefficient, is equal to the product of that coefficient by $\frac{1}{250}$, and by the number of degrees which indicate the mean temperature. But this latter being the half sum of the temperatures observed at the two stations, we see that the operation is reduced to the multiplying the whole sum by 35·944 metres, that is, by the product of the coefficient 17972·1 metres by $\frac{1}{2 \times 250}$ or by $\frac{1}{500}$.*

The second correction depends upon the thermometric effect of the heat with respect to the mercury of the barometer. Now, it is known that this liquid dilates itself about $\frac{1}{5412}$ of its volume, for each degree of the centigrade thermometer. Hence it results that if we compute from the temperature which obtains at the coldest station, the thermometric effect in question will be measured by the 5412th part of the length of the mercurial column at the same station, taken so often as there are degrees in the difference between the two temperatures. By adding the product to the number of centimetres exhibited by the barometer at the coldest station, the operation is reduced to what it would have been if the mercurial column had constantly retained the density it had while at the hottest station.

276. We shall apply this method to the determination of the height of *Mont-Blanc*, above the lake of Geneva, from the following data furnished by Saussure†. The barometer placed at 3 feet below the summit of Mont-Blanc, stood at 16 French inches and $\frac{1}{2}$ a line, which are equal to 0·4342 of a metre, and the thermometer of 80

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* The total effect which regulates the correction being the sum of the terms of the progression relative to the quantities whereby the densities of the air are altered by the heat, we have this sum by taking the mean term, which is the product of the mean temperature by the ratio $\frac{1}{250}$ of dilatation for one degree, and then multiplying that by the constant coefficient which represents the number of terms.

† Voyage dans les Alpes, No. 2003.

parts at — 2·3°, being equivalent to — 2·87° of the centigrade thermometer.

At the same time the barometer placed at Geneva, at 13 toises above the lake, was at 27 inches, 3 lines, 5·83 sixteenths, which make 0·7385 of a metre, and the thermometer of 80 parts at 22·6° answering to 28·25° of the centigrade thermometer.

To have the quantity with which the constant coefficient should be augmented, we must multiply the sum 25·33° of the two temperatures 28·25° and — 2·87° by 35·944 metres, and add the product 912·259 metres to the constant coefficient 17972·1 metres; which will give 18884·359 metres for the true coefficient.

Afterwards, to correct the height of the barometer to the coldest station, or that at the top of Mont-Blanc, for the variation of temperature; we must take the difference 31·12° between the two temperatures, multiply it by the height of the barometer at the coldest station, and divide the product by 5412; which will give 0·0025 of a metre, to add to 0·4342 of a metre: hence the corrected barometrical height will be 0·4367 of a metre.

Now, the difference between the logarithms of 0·7385 and 0.4367 is 2281673, which quantity multiplied by the corrected coefficient 18884·359 metres, gives for the vertical distance between the two stations 4308·79 metres, or nearly 2211 toises*. To know the total height of Mont-Blanc above the lake of Geneva, we have only therefore to add 51·65 metres, or 13 toises, 3 feet, which makes 4360·44 metres, or 2224·5 toises.

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* Let H the height of the barometer at the lowest station, h that which answers to the most elevated station, which we have supposed the coldest, T the height of the thermometer at the hottest station, t that answering to the coldest, and x the difference of height between the two stations; all these quantities (except the degrees of heat) being expressed in metres and fractions of the metre, the rule of which we have shewn, the application will be represented by this formula:

$$x = 17972{\cdot}1\left(1 + \frac{2\,(T+t)}{1000}\right)\text{Log.}\left(\frac{H}{h + \frac{(T-t)\,h}{5412}}\right).$$

We are acquainted with two trigonometrical measures of the same height, the one by Pictet, the other by Shuckburgh. The first has given 2238 toises, and the second 2257 toises: the result of Laplace gives 13·5 toises less than that of Pictet, and 32·5 toises less than that of Shuckburgh. But as these two latter results differ from one another by 19 toises, a very perceptible quantity, all that can be concluded from the comparison we have instituted is, that the formula of the celebrated French mathematician appears to lead to estimations erring a little in defect. It is a consequence of this that the numerical quantities included in the formula have not been determined, as we have already said, with sufficient precision. Besides, a correction has been hitherto neglected, to which the author of this rule proposed to have regard, namely, that which depends upon the aqueous vapour held in solution by the air, and which adds to the action of the temperature a new cause of alterations undergone by the law of aerial densities, such as it is given by the difference of the pressures alone. Careful experiments will accomplish the perfecting of this method, which has, over all others, the advantage of reducing to their true limits the quantities combined in the formula (z).

(z) The correction on account of the aqueous vapour has been recently made by M. *Daubuisson*: his resulting theorem, which is extremely complex, is published in No. 113. of the Journal des Mines. The formulæ of *Bouguer*, *Deluc*, and *Trembley*, are given by Prony in the 3d section of his Architecture Hydraulique. A modification of Laplace's rule from observations of M. Ramond, is given by *Biot* in the first volume of his Traité Elémentaire d'Astronomie Physique. The rules of M. *Deluc*, Sir *George Shuckburgh*, Professor *Robison*, and Dr. *Hutton*, adapted to English measures, may be seen in Book v. ch. 2. Gregory's Mechanics. M. Bettancourt, a Spanish philosopher, well known for his curious experiments on the force of steam, has deduced from those experiments a method of measuring altitudes, by means of a thermometer immersed in boiling water, (on the principle mentioned in par. 141.) which he thinks may be done with a precision, equal, if not superior, to that by the barometer. As to the results obtained by these and similar modes of admeasurement, relative to heights of mountains, &c. an extensive table is given in Von Zach's Geographische Ephemeriden, and an additional table in the 4th volume of

277. The same philosopher has conceived the happy idea of making the barometrical observations concur with the geographical measures, to ascertain in a more determinate manner the position of different places. This position, such as it is presented by the measures just mentioned, depends upon the intersection of two co-ordinates respectively perpendicular, one of which is the distance from the first meridian, or the longitude, and the other the distance from the equator, or the latitude. Laplace conceived a third co-ordinate perpendicular to both the former, which measured the vertical distance between the same point of intersection and the level of the sea. He proposes to take for France this level at Brest, where the mean height of the barometer is nearly 76 centimetres. There might be made in every place a great number of barometrical observations, during a year or two, and the mean between all these observations would give the elevation of the place proposed above the level of the sea. The observer might choose, in each respective country, the mean height of the nearest river for the level to which he would refer his observations. A similar labour executed by skilful observers, and with accurately constructed barometers, would offer very interesting results in regard to the topography of different countries (*a*).

Hutton's translation of Montucla's Recreations. From these tables it appears that there are, at least, 16 mountains upon our globe, whose altitudes each exceed 2000 toises, and indeed 3 whose altitudes exceed 3000 toises; these are Chimboraço, 3220 French toises; Cayambé Orcou, 3030; and Antisana, 3020 toises. Some important corrections to the French estimates of altitudes by the barometer, &c., on account of their assuming 28 French or 29·9 English inches, instead of 30·08 English inches, for the mean height of the barometer at the level of the sea, are suggested by Mr. *Kirwan*, in his tract " On the Variation of the Atmosphere." Tr.

(*a*) M. *Girard*, Chief Engineer of Bridges and Highways in France, has published a memoir in the 17th vol. of the *Journal des Mines*, recommending this method of Laplace. He proposes that in order to save expense to the French nation, the engineers of bridges and highways should be employed in the work. His particular directions are in the main judicious; but as they are applicable to France alone, they need not be repeated here. Tr.

2. *Effects of Caloric upon the Air.*

278. We have now to contemplate the phenomena which result from the force of caloric, either to dilate the air or to augment its elasticity. If we commence by supposing a mass of heated air, which is not confined by any obstacle, it will be easy to conceive that this air will, by dilating itself, acquire an augmentation of volume which will diminish its specific gravity, in such manner that if it be surrounded by a colder air, it will arise, and will presently be replaced by a portion of that surrounding air; and if the heat continue to act in the same space, it will establish a kind of circulation, in virtue of which a denser air will continually take the place of a rarefied air.

279. The action exerted by heat upon the air in apartments with chimneys, furnishes us with a familiar example of this phenomenon. The particles of that air diffused about the fire-place, becoming respectively lighter on account of the rarefaction, a part will rise into the tube of the chimney, and the other will move towards the top of the room: at the same time fresh air will arrive at the lower part, to fill the place of the ascending air, and there will result an uninterrupted succession of two contrary currents; the one superior, which carries the air from the chimney; the other inferior, and carrying the fluid towards it. The velocities of these two currents diminish in proportion as the strata approach a certain mean height where the air is stationary. We may observe the effects of this double current, by opening the door of the apartment and placing the flame of a candle alternately towards the bottom and towards the top of the opening; when we shall see the flame incline first inwards, then outwards, and at a certain intermediate height it will be immoveable.

280. The perpetual succession of these two airs, so long as the action of heat is kept up, has furnished a plausible explication of a species of wind which blows continually in the torrid zone, and is called *east wind.* Some authors have imagined they had found the cause in the attraction exerted by the sun and moon upon the atmosphere; but it is demonstrable that this attraction can only produce in the air simple oscillations analogous to those of the flux and reflux of the sea, being almost insensible, and not a motion perceptible and uniform in its direction.

The most general opinion is that the east wind is occasioned by the dilatation of the air rarified by the action of the sun; and among the different ways in which it has been conceived that this action is exercised, we shall confine ourselves to the exposition of that which appears most simple and natural.

The sun, which we will suppose in the plane of the equator, heats and rarifies very perceptibly the part of the atmosphere which it reigns over. This rarified air rises above its level, and from the tendency possessed by all fluids of re-assuming their level, it diffuses itself over the columns situated towards the poles, while a colder air part of those same columns pours in beneath towards the equator. There will be formed, therefore, in either the boreal or the austral hemisphere, two currents; one superior, which sets from the equator towards the pole, the other inferior, and it proceeds from the pole towards the equator. The moleculæ of these currents are solicited at once by two forces, one of which acts in the direction of its respective current, and the other arises from the rotatory motion of the atmosphere: and it is evident that the velocity produced by this second motion was originally so much the smaller in each molecule, as the parallel of which it constituted a part was farther removed from the equator.

Now, if we consider a particle taken in the inferior current whose direction tends towards the equator, it will be easy to conceive that this particle arrives at each of the parallels situated upon its path, with an angular velocity* less than that of the correspondent point taken at the surface of the earth. The terrestrial objects which present themselves to the passage of the inferior current, ought therefore to be struck with the excess of their velocity: and it will be the same with regard to an observer, who, thinking himself immoveable, and referring the excess of his proper velocity, in an opposite direction, to the current he encounters, will receive the impression of a wind which will appear to him to come from the east, because the rotatory motion of the earth is directed from the west towards the east.

It will be the reverse of this with respect to the superior current which sets towards the pole. Each of its particles having more velocity than that of the terrestrial point above which it has arrived, will outrun that point in its progress towards the east; whence there must result from this excess of velocity a real west wind, while the inferior wind is a simple appearance, although it produces a complete illusion *(b)*.

281. The heat which augments the volume of the air when it has the faculty of extending itself, adds to its elastic force, when its volume remains unalterable, that is to say, it then exerts a greater effort contrary to the obstacle which confines it. On this subject we have several interesting results obtained by Amontons,

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* This name is given to the velocity of a body which moves in a circular manner about a point. When the rotation is uniform, the velocity is proportional to the angle, which is measured by the arc described by that body in a given time.

(*b*) The reader will find more on the subject of winds in par.318—328 of this volume. Tr.

one of those learned men who best knew the art of bringing nature into action by experiments, and of making her speak at the same time to the eyes and to the mind.

282. This celebrated philosopher, having attempted to measure the augmentation of elasticity experienced by the air between certain limits of heat, has found that from the moderate temperature which predominates during the spring or the autumn, to the degree of boiling water, the elasticity of the air, confined at first by the mean pressure of the atmosphere, became augmented by about its third; so that the force necessary to retain the air in the same space, without sensible increase of volume, is equivalent to the weight of 28 French inches of mercury, plus 9⅓ inches, or 37⅓ inches, when the air has taken the heat of boiling water.

Whatever was the mass of air employed, provided that it was charged with the same weight, the augmentation of elasticity always obtained in the same ratio; whence this principle resulted, that if unequal masses of air are charged with equal weights, their elastic force will be equally increased by equal degrees of heat.

The experiments shewed also that if equal masses of air were charged with unequal weights, their elastic force would increase proportionally to those weights, by the same augmentation of heat. Thus, a mass of air which, being at first charged with a pressure of 30 inches, having acquired an augmentation of elastic force of 10 inches, in the passage from a temperature of about 14 degrees to that of boiling water, would acquire one equal to 20 inches when the primitive pressure was equivalent to 60 inches.

283. Amontons, in applying the theory to these principles, has discovered the link which united them, both

to one another, and to the results of Mariotte, concerning the relation between the degrees of contraction of the air and the weight with which it is charged.

For when, in the experiments of Mariotte, unequal masses of air which were supposed to have been always taken in the same state of density would support equal weights, they would contract themselves proportionally to the volumes they had at first; whence it follows, that after the contraction they would retain the same density; so that if the primitive volume of one of them were four cubic inches, and was found reduced to three inches, another whose volume answered at first to eight cubic inches would then occupy no more than six. But when there was applied to these measures equally compact, a like degree of heat, the fire would act no more to dissipate the particles of one than those of the other; and thus the augmentation of the elastic force, which depended upon this separation, would be the same.

On the other hand, equal masses of air charged with unequal weights, would contract themselves in the ratio of those weights; and when there was applied to them the same degree of heat, the more particles of air there were collected into the same space, the more considerable was the effort of heat requisite to scatter them: and thus the augmentation of the elastic force conformed to the ratio of the condensations, that is to say, it was proportional to the compressing force.

If it be considered that Amontons wrote in 1702, at the epoch of a philosophy which had grown old in many respects, we shall allow that there was much ingenuity and force of mind in these views, which prepared long before-hand the discoveries which more completely developed knowledge has clearly presented in these latter times.

We ought not to omit mentioning that Amontons was likewise the first who observed the remarkable phenomenon presented by water, which, when once arrived at ebullition, ceases to heat itself farther, however long time it is left over the fire, and whatever may be the activity of that fire.

284. Amontons conceived the idea of applying these different discoveries to the construction of a comparable thermometer, by means of which one might transmit, so to speak, to posterity the observations which had been made on the temperature of different climates; instead of which, the different instruments of this kind had, previous to that, no mutual relation, and offered only local and unconnected indications. The explanation we shall now give of Amontons's process, will serve to furnish an idea of that which he had employed to determine the augmentation of elasticity which the air acquired by the action of heat.

He made use of a tube whose inferior part, which was bent up, was terminated by a ball; the open branch was about 47 inches high. He chose for the construction of his thermometer the moderate temperature we have spoken of, namely, that of spring or of autumn. By an ingenious process, which consisted in soldering with mastic, to the top of the open branch, a, second tube likewise bent up, and which had an enlarged part (*renflement*, belly or swelling out) towards the place of its junction with the other tube, he succeeded in introducing into this about 28 inches of mercury, and at the same time in so condensing the air comprised in the ball that its level surface was situated towards the beginning of that ball; he then took away the tube which had served to introduce the mercury, and there remained nothing more than to apply the other to a plate divided into inches and lines, estimating from the level of the air in the ball.

He took care to give to the ball a diameter incomparably greater than that of the tube; and hence, when the air included in this ball came to be heated by the temperature of the atmosphere, it extended itself, in fact, in the shortest branch, and forced a part of the mercury which it contained to pass into the longest branch. But since the quantity of the dilatation might be neglected, because of the great capacity of the ball, the volume of the air was not considered as having changed; so that the augmentation of elasticity, as it was measured by the lengthening of the mercurial column, was, as to sense, proportional to the real augmentation of elastic force.

The interior air had therefore to support, at the moment of the construction, a pressure of about 56 French inches; namely, the pressure of the atmosphere, and that of the 28 inches of mercury introduced into the tube. The same air, by passing to the heat of boiling water, would have been capable of sustaining a pressure of about 74 inches, that is, a third stronger than that of 56 inches. This latter (74 inches) was the fixed term to which the construction of the instrument was referred, so that the height of the column shewed the greater or less approximation of the temperature to that of boiling water.

Although the quantity of air comprised in the ball was indifferent, yet it was adviseable, to render the different thermometers more comparable, to take balls whose diameter was always in the same ratio with that of the tube; and this added to the difficulty of the construction. Besides, the mean temperature, whence he commenced his operations, did not present a sufficiently constant term. It was necessary, moreover, in consulting the instrument, to have regard to the height of the barometer, in order that the requisite correction might be made for the variation of the mercurial column above or below 28 French inches. Lastly, this thermometer became embarrassing on account of the magnitude of its dimensions. It was, however, the first whose execution had been directed towards the true perfection of that instrument; and it comprehended a fixed term of heat which Reaumur employed only secondarily, and to which succeeding philosophers have adhered.

285. The results of Amontons, relative to the augmentation of elasticity experienced by air when it was heated, gave at the same time the quantity whereby that fluid was dilated by the action of the same cause. This dilatation was also a third, from the mean temperature to that of boiling water; but the fluctuations in this first temperature necessarily threw some uncertainty upon the consequences deduced from the observations. Since that time many learned men have occupied themselves upon the same object, by taking the degree of thawing ice and that of boiling water for limits of temperature, and the mean pressure of the atmosphere for that which would act uniformly upon the air: but the great diversity which is found between their results made it desirable that this point should be subjected to a more rigorous examination. Gay-Lussac has undertaken to perform this task; and by a series of experiments, made with much care and precision, has been enabled to determine not only the dilatation of the atmospheric air, between the two limits we have spoken of, but even those of the various other gases both soluble and non-soluble; and what adds a new degree of merit to the results he has obtained, is the uniformity of the law of dilatation to which he has been conducted*.

286. Previous to detailing the results in question, this philosopher discussed the different means employed before his time to attain the same object; and he remarked that the cause which had most contributed to render them faulty, was the presence of some drops

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* Annales de Chimie, by Guyton, Monge, Berthollet, &c., No. 128, pa. 137 et seq.

of water which had lodged in the apparatus. This water, occupying by its vaporisation a volume near 1800 times (235) more considerable than in the state of liquidity, displaced a great part of the air included with it in the same ball; so that much too high a dilatation was attributed to the air, by supposing that it alone filled the capacity of the ball, in which the temperature had attained the degree of boiling water. Gay-Lussac has employed different modes of proceeding with respect to insoluble gases and to those which are soluble.

287. The reader shall first see to what his method is reduced, as it regards the former: he took a very dry balloon, into which he introduced the gas whose dilatation was to be determined; this balloon was then heated to the term of boiling water, and when the dilatation had produced all its effect in expelling a part of the gas, he cooled it to the degree of thawing ice, and at the same time left to enter into the balloon as much water as the presence of the remaining gas would permit; and the remark connected with this process was, that the gas in its different states ought always to be brought to an equilibrium with the constant pressure of the atmosphere. This granted, the volume of water which is introduced into the balloon may represent the quantity by which the remaining air is susceptible of dilating itself, on passing from the temperature of thawing ice to that of boiling water. The balloon was weighed first in that state, then after being filled with water, and lastly after it was emptied. The difference between the weight of the empty balloon, and that of the balloon full of water, gave the capacity of the balloon; and the difference between the weight of the empty balloon, and that of the balloon containing a quantity of water equal to the space left free by the condensation of the air, gave the mea-

sure of that volume; after which it was easy to determine the ratio between the volumes of the air in the two extreme temperatures.

288. By this kind of operation Gay-Lussac has found that atmospheric air dilates itself, on passing from the temperature of thawing ice to that of boiling water, in the ratio of 100 to 137·50, or a little higher than that of 2 to 3; whence it results that the dilatation between those limits is $\frac{37\cdot5}{100}$, or $\frac{80}{213\cdot33}$ of the primitive volume. Hydrogenous, oxygenous, and azotic gas, when subjected to the same experiments, each furnished results absolutely similar.

289. To determine the dilatation of soluble gases, Gay-Lussac has had recourse to a method as simple as ingenious, by assuming for a term of comparison the dilatation of one of the insoluble gases which had been the object of the preceding experiments. His apparatus was composed of two tubes, graduated accurately lengthwise and immersed vertically in a bath or vessel of mercury: one of the tubes contained atmospheric air, the other the gas which it was proposed to try; and the two fluids rose in the tubes to the same height. This apparatus was then placed in a stove whose temperature was elevated progressively, and the two fluids were seen to rise in their respective tubes, so as always to correspond very exactly to the same divisions; which proved the equality of the dilatations. The fluids which were the object of this comparison were carbonic acid gas, muriatic acid gas, sulphureous and nitrous gas. This uniformity in the progress, followed by the different gases while dilating, thus presented a strong reason from analogy to think that the vapours would be subjected to the same law. Gay-Lussac contented himself with a single experiment relative to this point, and that served rather as an example than as a proof. He chose the vapour of sulphurated ether; and,

by employing the same process as for the soluble gases, he observed that the progress of the dilatation was absolutely equal in both.

These results accord with those of the experiments undertaken by Dalton, about the same time, in England, and relating to the same object, but of which the French chemist could not have any knowledge when he imparted his labours to the National Institute of Sciences and Arts. About fifteen years before this, Charles obtained similar results for insoluble gases; but his experiments relative to the soluble gases presented him with a particular dilatation for each of them, and under this point of view his results differed greatly from those of Gay-Lussac.

Thus, the dilatability of the various gases and vapours, by the action of heat, does not in any respect depend upon their nature, but solely upon their elastic state. Philosophy is never more interesting and engaging than when the contemplation of natural phenomena lead to those properties which generalise them, and shew us that all are comprehended under some one whole.

290. We may assign a reason for this uniformity in the law to which the dilatations of gases and vapours are subjected, if we consider that the affinities exerted mutually between the particles of each of such bodies in the liquid state, and which differently counterbalance the elastic force of the caloric according to the different natures of those bodies, are entirely destroyed in consequence of the passage to the state of elastic fluidity. There then remains nothing therefore, but the elastic force of the caloric, which, finding the particles of all the fluids (so to speak) equally disposed to obey it, must produce a uniform progress in the dilatations which take place between the same limits of temperature.

291. The researches which we have explained only

give the ratio of the dilatations for the two limits which answer to the extremes of temperature. It remains to determine with precision the coefficient that represents the dilatation relative to each degree of the thermometer. Gay-Lussac soon found that this coefficient was not constant, and he proposed to undertake a new series of experiments to ascertain the law of its variations.

292. Dalton, while continuing his experiments upon fluids, obtained another result no less remarkable, in so far as it reduced to one and the same scale the law followed by the elastic forces of different fluids when compared one with another, in proportion as they varied with the temperature*. We shall shew in what his result consists: if we take for a common term the force which sustains an equilibrium with a given force, such as the medium pressure of the atmosphere, the variation of that force between two determinate temperatures is the same for all the fluids. Thus, the aqueous vapour, which has a temperature of 100° c† (80° R, 212° F), or the term of boiling water, is capable of sustaining a pressure of 76 centimetres (28 French or 29·9 English inches), loses the half of its force by a diminution of 16·6° c (13·3° R, 29·88° F) in its temperature; and that same force is found doubled by an augmentation of temperature equal to 22·2° c (17·8° R, 39·96° F). But, the vapour of every other fluid loses equally the half of its force by cooling 16·6° below the particular term of its ebullition, and acquires a double force by being heated 22·2° above the same term.

293. Let us choose another relation, and apply it to the vapour of ether and that of water. It is known

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* Bibliotheque Britan., No. 160, vol. XX. p. 343 et seq. Memoirs of the Manchester Society, vol. V.

† In all the indications of temperature which will be here given, the letter c denotes the centigrade thermometer, R the thermometer of Reaumur, and F that of Fahrenheit.

that the ether commences ebullition at 38·8° C (31·4° R, 101·84° F); that is to say, its vapour sustains a pressure of 76 centimetres: the same vapour cooled down to 16·6° C (13·3° R, 61·88° F) can only sustain a pressure of 30 centimetres. Such is also the pressure sustained by aqueous vapour at 77·8° C (62·2° R, 172° F); and, if we take the difference between 16·6° and 38·8°, which indicates with respect to ether, the term of ebullition we shall find that it is 22·2°, the same as exists between 77·8° and 100°, which answers to the heat of boiling water.

On the other hand, the vapour of ether heated up to 63·8° C (51·4° R, 146·84° F), balances a pressure of 16 decimetres; and aqueous vapour has the same force when the temperature is denoted by 125° C (100° R, 267° F). Now, each of these two temperatures differs 25° from that which corresponds to the ebullition of its respective fluid; that difference being equal to 63·8°—38·8° for the vapour of ether, and 125°—100° for the aqueous vapour. We shall soon have occasion to explain other results, which will present fresh proofs of the sagacity of the same philosopher.

3. *On Evaporation.*

294. We are now arrived at one of the effects of the air, in the knowledge of which the progress of Natural Philosophy has been the most tardy. Water exposed uncovered in a vessel diminishes its volume by little and little, its moleculæ as they abandon the general mass raising themselves into the atmosphere. This effect is known under the name of *Evaporation:* but by what mechanism of nature is it produced? Here philosophers have divided between different opinions; most of which tend to ascribe to fire the principal

influence in the phenomenon; either because they have confounded evaporation with vaporisation, or because they have observed that a greater quantity of water was evaporated when the air was more heated.

295. Some philosophers thought that the moleculæ of water, extremely divided by fire, and acquiring a considerable augmentation of surface, with regard to their volume, empowered the air to seize them, by striking them and wrapping them up in the contours of the little spiral plates of which it was composed. According to others, the fire by dilating the moleculæ of the water, renders them specifically lighter than the air, so that their ascent in that fluid is only an ordinary phenomenon of hydrostatics.

296. In the midst of this conflict of opinions, to which we might likewise add others which have little foundation in nature (*c*), the true cause was suggested

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(*c*) Many ingenious men, as Eeles, Beccaria, and others, have attempted to explain the phenomena of evaporation agreeably to the principles of electricity. One of the most plausible statements of this theory of evaporation we have met with is contained in *Williams's Remarks on the Climate of Great Britain.* As this is a work which may not fall into the hands of many readers of the present treatise, it may not be amiss to present Mr. Williams's ideas in his own language.

" Philosophers are agreed that most bodies are surrounded with a peculiar fluid, more rarified than common air, which forms around them a kind of atmosphere to a given extent; various optical and electrical experiments confirm this opinion. The vapourous vesicles themselves demonstrate the existence of a similar atmosphere surrounding them, by the facility with which they move on the surface of water; a medium supposed congenerous with them, without uniting with it; for if they were in immediate contact, they would, by the force of attraction, immediately unite with the medium on which they float: the same may be observed of dust blown over the surface of any liquor. What, then, is the nature of this atmosphere? Is it fire? so far, then, it would not be observable, as it is, in clouds, which are nothing but an accumulation of such vesicles apparent in the most rigorous winters. The diminution of cold during winter, which accompanies rain, indicates that these vesicles have, in forming water, relinquished a portion of fire in a certain state, employed in their suspension. Is this the electric fluid? Yes. The interior of these vesicles are *hollow spherules,* for they appear larger when they are heated: they by Muschenbroek. "The air and the water," said that celebrated philosopher, "attract each other reci-

must therefore contain a fluid expansible by heat, and their lightness excludes the idea that it is *dense* air. This fluid is doubtless the *same as their atmosphere;* and if the outward envelope, or atmosphere, be removed by any conductor, the internal air tries to escape, which produces the attraction of each other to form larger drops. When these vapours are condensed by extreme cold, the water which forms their envelope crystallises sometimes into snow or hail, or, when it attaches itself to solid bodies, into ice; in this state it is *concrete vapour.*

"Notwithstanding the abstract reasonings of Desaguliers, and others, against the globular shape of vapourous particles, observation demonstrates this to be the form they invariably assume. They may even be seen, in some cases, by the naked eye. Thus, exposed to the rays of the sun, and in a place where the air may not agitate, a cup filled with some hot aqueous fluid, of a black or dark colour, as coffee for instance, there will proceed from this liquor a vapour more or less dense, which will ascend to a certain height, and then disappear. The eye of an attentive observer will easily discover that this vapour is composed of numerous *rounded whitish grains* detached from each other. Would we wish for more light on the subject, we must view them with a double convex lens, of about one inch, or an inch and a half focus; if we observe attentively with this lens what passes upon the surface of the liquor in the abovementioned state, we shall perceive *spherical bubbles* of different magnitudes to arise from the surface, by a different celerity of motion; the smallest, or fine, will rise with rapidity and become invisible, while the larger, or more gross, will fall back into the cup, without mixing with the liquid, rolling on the surface like light dust, subject to the impulse of air; for on breathing we may drive them from side to side of the vessel; nay, when there is no perceptible agitation in the air, we may see these globules suddenly in motion, the smaller coalescing with the larger, which still preserve their station on the surface: others which were elevated in air, are seen descending and coalescing as the former, or sometimes again reuniting with the liquor which first gave them birth. The lightness of these spherules, their whiteness, and different appearance from *solid globules,* leaves no doubt as to their nature. It is sufficient to see them to obtain conviction that they are *hollow spheres,* similar to the bubbles apparent on agitated saponaceous suds. These being specifically lighter than the surrounding medium, consequently ascend till they attain the higher regions; in this state they do not destroy the diaphanous state of the atmosphere; for they do not change the apparent form of the planets. And this arises from the fact, that rays of light, passing through extremely minute meniscous transparent bodies, suffer no sensible deviation or aberration; their electricity is, in this stage, in the weakest state in these colder regions. And the rapidity with which this solution of vapour is effected, forms a probable criterion to judge wheprocally, and are dissolved the one by the other. As soon as the particles of water begin to separate themselves, they are attracted by the air into which they are dispersed; as happens in all solutions, where there is the same mixture and dispersion of parts*." But Muschenbroek contented himself with indicating this cause, twisting it at the same time into an association with many others *(d)*.

297. It was reserved to Le Roi, of Montpellier, to present this cause in all its generality, to render the existence palpable, to follow it in its different modifi-

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ther the day will be fair or showery; and the quickness or slowness with which the solution takes place, appears to depend on the greater or less proportion of electric matter present. They are now condensed, a number of their minute particles unite by the law of cohesive attraction, and form a globule of greater bulk, but whose surface is not increased in the same ratio; consequently the intensity of the electricity becomes greater, as shewn by the Franklinean experiment of the *can and chain*. These enlarged particles do not permit all the rays of light to pass, like the smaller ones; the transparency of the sky is therefore destroyed, and the combined arrangement of a series of these larger particles forms a cloud or fog. These enlarged particles are kept asunder by the repulsive power of electricity, in the same way that two pith balls are when electrified by art; otherwise they would unite from the attraction of cohesion, and immediately form drops of rain. Clouds are sometimes found negatively electrified, owing to the influence of an atmosphere strongly electrified positively; as is explained by the phenomena of the Leyden phial. The particles of vapour, forming such a cloud, are likewise kept from coming into contact by negative repulsion."

These passages are sufficiently illustrative of Mr. Williams's theory: it is certainly ingenious; but is, notwithstanding, exposed to many objections. Tr.

* Essai de Physique; Leyden, 1751, tome II. pa. 721.

(*d*) It seems the Abbe Nollet started a similar opinion, though without much pursuing it, in his Leçons de Physique Experimentale, first published in 1743: he offers it as a conjecture, that the air of the atmosphere serves as a solvent or sponge, with regard to the bodies that encompass it, and receives into its pores the vapours and exhalations that are detached from the masses to which they belong in a fluid state; and he accounts for their ascent on the same principles with the ascent of liquors in capillary tubes. On this hypothesis, the condensation of the air contributes, like the squeezing of a sponge, to their descent. Tr.

cations, and thus to exhibit in a new light the simplicity of the picture of nature, by causing one of its most extended phenomena to fall under the universal power of attraction*.

298. The whole doctrine of this philosopher is reduced to the following principle: the air dissolves water in the same manner and with the same circumstances that water dissolves salts; so that as the water, by being heated, becomes capable of dissolving a new quantity of salt, and abandons, by cooling, a part of that which it had dissolved; in like manner, as the air becomes heated or cooled, it takes up more or less water before it has arrived at its point of saturation.

The experiments exhibited by this philosopher in proof of the principle before us, are such as are repeated spontaneously every day. They have been seen a thousand times, yet have the observers disregarded them.

299. The author exposed at his window a white glass phial, exactly stopped up; the temperature being then at 20 degrees above the zero of the thermometer in 80 parts (77° F). Some time after, the thermometer having descended during the night to 15 degrees (68¾F.), Leroi perceived that a part of the water contained in the air with which the bottle was full, had disposed itself in form of little drops, upon the upper parts of the interior of the vessel, which being most exposed ought naturally to cool first. This species of dew became much more abundant, when the thermometer had descended to 6 degrees (45½°F.). The air, by heating again during the day, re-dissolved the water which had been precipitated during the night. This air represented all the rest of the atmosphere; and the vessel which was the subject of the experiment did nothing else than render manifest to the eyes what

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* Melanges de Physique et de Medecine, p. 1 et seq.

was otherwise in a manner insensible. The same experiment repeated and varied with every attention requisite to render it decisive, has constantly given analogous results.

Leroi afterwards investigated the means of determining the degree of saturation of the air relative to a given state of the atmosphere. To obtain this he poured into a large crystal cup, well dried on the outside, water sufficiently cold to occasion upon the exterior surface of the cup cooled by the vicinity of such water, a precipitation of that which was held in solution in the surrounding air; when the temperature of the water had risen a half degree, he poured it into a fresh vessel, and observed the term where the precipitation stopped: that term indicated the degree of saturation of the air. The author ascertained, by means of this experiment, that the direction and force of the wind caused a very perceptible variation in the degree of saturation; that it was lower with a north than with a north-west wind, and that in both cases the force of the wind contributed to a still farther depression.

300. Although the comparison made by Leroi of the manner in which the air dissolves water, with that whereby water dissolves salts, be exact as to the foundation, it is, nevertheless, not entirely applicable in all respects. There is this difference between the two phenomena, that a salt which is dissolved in water passes from the solid to the liquid state, in such manner that its specific gravity does not undergo any considerable variation; while water by evaporating passes from the liquid state to that of an elastic fluid which diminishes its density in the ratio of 1 to more than 1000 *(e)* (235,286,317).

(e) M. Leroi's theory was first published in the Memoirs of the French Academy for the year 1751. Yet Dr. Hamilton of Dublin transmitted to the Royal Society in 1765, a long Dissertation on the nature of Evaporation, in which he proposes and establishes this theory of solution; and

301. We are now able to establish an exact comparison between vaporisation and evaporation. The first is occasioned by the circumstance that the elasticity of the caloric, which acts upon the moleculæ of water, is sufficiently powerful to overcome the pressure of the air. In evaporation, this same air which, on one hand, opposes itself by its pressure to the elastic force of the caloric tending to reduce water to vapour, seconds it, on the other hand, by the affinity which it exerts upon that liquid.

302. The evaporation is so much the more abundant, *cæteris paribus*, as the water by presenting to the air a greater surface, multiplies farther its points of contact with that fluid. The inhabitants of some countries avail themselves of this fact, in order the more speedily to extract sea salt from the air which holds it in solution. They first cause the water to fall upon thorn faggots, where it divides itself as into a very fine shower, which presenting to the air it traverses the facility of acting upon it by its numerous contacts, it becomes evaporated in great part, so that the water that arrives at bottom is found highly charged with salt. This water is then carried into great cauldrons, where it is exposed to the action of fire to complete the evaporation.

303. The parts situated at the surface of water being the only ones that are subject to evaporation, the quantity of this evaporation in full vessels whose orifices are

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though other writers had been prior in their conjectures, and even in their reasoning on this subject, Dr. Hamilton assures us, that he has not represented any thing as new which he was conscious had ever been proposed by any one before him, even as a conjecture. Having evinced the agreement between Solution and Evaporation, he concludes, that Evaporation is nothing more than a gradual solution of water in air, produced and promoted by attraction, heat, and motion, just as other solutions are affected. It is unnecessary to relate more of the doctor's hypothesis in this place: those who wish to compare it with Leroi's in its several particulars, may consult Hamilton's Essays, pa. 33, &c. Tr.

unequal, is proportional to the magnitude of those orifices, provided that the heat and other circumstances are the same in regard to all the vessels. Muschenbroek has found, it is true, that, with equal surfaces, the water contained in a deep vessel is evaporated more rapidly than in a vessel which has less depth*. But this difference arose probably from this, that among the causes of variation undergone by the temperature of the surrounding air, those which tended to depress it were the most frequent. For it would hence result that the water contained in the deepest vessel, being composed of a greater number of strata or laminæ between the bottom and the surface, followed more slowly the variations of temperature, and therefore lost less speedily the heat which it had once acquired, and whose presence would accelerate the evaporation†. Farther, the difference in question was only sensible in open air; it being observed that it vanished in apartments where the temperature experienced only slight variations.

304. Ice also is susceptible of evaporation, but so much the less as it is more cold: if some philosophers have imagined they have perceived the contrary, it is probably because they made their experiments during a dry parching wind, which by rapidly renewing the points of contact, augments the dissolving faculty more than the cold tends to diminish it. Nevertheless, Muschenbroek and Wallerius have observed that the evaporation of water increases during congelation: but this effect is only instantaneous; it arises from the heat which is then developed, and which, by passing into the surrounding air, raises its temperature.

305. From the principle established by the experiments of Leroi, several phenomena of familiar observa-

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* Additions to the Memoirs of the Acad. del Cimento, vol. II. pa. 62.

† Novi Commentar. Petropol., t. II. p. 134.

tion may be explained with great facility. The mere statement of these experiments enables us to conceive the manner in which dew is precipitated from the air, when the temperature of that fluid, little distant during the day from the degree of saturation, has descended during the night below that degree. It is a matter of common observation that in frosty weather the glass windows of apartments are wetted within. As the exterior air is then colder than that within, the caloric contained in the part of this latter, which is in contact with the glass, passing through its little thickness with facility, diffuses itself on the outside to satisfy its tendency towards an equilibrium. It results that the interior air abandons a part of the water which it held in solution, and deposits it on the surface of the glass. The reverse of this happens in a thaw when the exterior temperature is highest, whence it is said that our apartments are then cold; the humidity in that case appears on the outside of the glass. We may also conceive why the breath of animals, hotter during the winter than the air into which it is respired, becomes visible under the form of a vapour produced by the water which it gives out during the process of cooling. All nature is full of this kind of facts, of which it will be easy at the first glance to trace the analogy with the preceding.

306. The way in which water influences the state of the air, after that fluid has raised it up by evaporation, has already drawn the attention of many celebrated philosophers. Dalton, in the midst of his numerous enquiries relative to gases and vapours, has undertaken, in connection with this subject, a labour whose results are the more interesting as they extend to the constitution of all the mixtures that elastic fluids are capable of forming, by uniting one with another.

307. But let us first terminate our account of what

was previously known with regard to evaporation. The water which has undergone this effect is no longer in the state of liquidity; it has passed to that of an elastic fluid, and is, in truth, in the same state as if it had undergone vaporisation under an air so far rarefied as to present no obstacle to ebullition. Saussure had even ascertained that its presence augmented the elasticity of the air, and had made experiments with a view to estimate the augmentation of elasticity which took place, in consequence of the mixture of a given quantity of vapours at a given temperature*. To arrive at this evaluation, he introduced, by many distinct efforts, a piece of moistened linen into a determinate mass of air, which had been previously desiccated as far as possible; and he observed that this air, in proportion as it dissolved the water, produced a gradual elevation in a column of mercury submitted to its pressure. He found, among other results, that at a temperature of 15° of Reaumur's thermometer (70¾° F) the quantity of vapour capable of saturating the air communicated such an increase to the elasticity of that fluid, that instead of a pressure of 27 inches, which had before balanced it, it then sustained 27 inches, 6 lines. From this observation he concluded, that the vapour diffused through the air, subjected to the experiment, was an elastic fluid capable of sustaining alone a pressure equal to the augmentation of elasticity which it communicated to the air; so that in a vacuum it would really have sustained that pressure.

308. Saussure found, moreover, that at the same temperature of 15° R, a cubic foot of air, previously well freed from humidity, became saturated by a quantity of vapour weighing about 10 grains.

309. It follows, from what has been said, that a mass

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* Essais sur l'Hygrométrie, Nos. 108 et seq.

of air saturated with water in a vaporised state, at 15° R, requires a pressure of 27 inches 6 lines (French) to confine it in the space which it occupied before saturation, under a pressure of 27 inches. If, therefore, it be as yet only loaded by this latter pressure, the moleculæ of the vapour will drive asunder those of the air by their elastic force, while that fluid retains them by its affinity in a state of suspension, and the volume of the mass will be augmented by $\frac{1}{54}$; and since the density of the vapour is to that of the air, according to Saussure, nearly as 10 to 14, the volume will increase in a greater ratio than that of the augmentation of the mass; whence it must be concluded that the specific gravity of the air diminishes in proportion as it holds a greater quantity of water in solution. Newton, in his optical queries, where we find a multitude of conjectures, which are as so many precious gems, the unfolding of which was reserved to other times, remarks that the true air is heavier than vapours, and that a humid atmosphere is lighter than a dry one, taking equal quantities*.

310. We come now to the results of the investigations undertaken by Dalton. This celebrated philosopher proposed to himself to enquire, by a general method, in what manner any gas is dilated, or, which amounts to the same, to what degree its elasticity is found augmented, at a given temperature, by its union with a vapour of known elasticity, at the same temperature.

311. In the experiments with this object in view†, he made use of a strait glass tube, closed at one extremity, and divided into equal parts. He introduced at the bottom of this tube some drops of the liquid, such as water, which he wished to subject to the

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* Optice Lucis, lib. III. quæst. 31, p. 322.

† Bibliotheque Britan., No. 160, vol. XX. p. 328 et seq.: Manchester Memoirs, vol. V.

experiment, and inclosed in the same tube a gas, such as air, by charging the latter with a column of mercury more or less high, according to the subject he proposed to investigate. He next immersed the closed extremity of the tube into water of a given temperature, and afterwards observed by the motion of the mercury, the expansion of the gas and of the vapour united with that gas. We shall here exhibit the formula which he deduced from his observations.

312. Let us denote by P the pressure sustained by the gas alone, before the experiment, at the given temperature, P′ that which the vapour alone is capable of sustaining at the same temperature, V the primitive volume of the gas, and V′ its volume after dilatation, at the term where the mixture is in equilibrio with the pressure P. Supposing the three former quantities known it is required to determine V′.

Now we must conceive that in the first instant, wherein as yet the air occupied only the volume V, there is introduced an equal quantity of vapour; and since the force of that vapour when alone makes an equilibrium with the pressure P′ which may also represent the elasticity of the vapour, we are at liberty to suppose that this elasticity was employed in sustaining a part P′ of the pressure P with which the gas alone was previously charged, so that this fluid is pressed by no more than a force equal to P—P′. It will dilate itself therefore by its excess of elasticity. But as it is dilated it forms a new quantity of vapour which is always proportional to the augmentation of volume, so that the pressure to which this vapour makes an equilibrium at all elevations, or, which comes to the same, its elasticity is constantly equal to P′. The gas will continue, therefore, to dilate itself till it reaches the limit where the residue of its elastic force is no longer capable of balancing the pressure P: and since the dilatations or the volumes are in the inverse ratio of the pressures, we shall have $v' : v :: p : p - p'$; whence we find, $v' = \frac{vp}{p - p'}$ and $v' = v + \frac{vp'}{p - p'}$ (*f*).

Let us suppose that, the gas being the common air, and the vapour that of water, we have $p = 27$ inches, $p' = \frac{1}{2}$ inch, and let us assume $v = 1$. The formula will give $v' = \frac{27}{27 - \frac{1}{2}} = \frac{54}{53}$; that is to say, in this case the air is dilated in the ratio of 53 to 54, which corresponds with the result of Saussure (309).

Let $p = 20$ inches, and $p' = 10$; we shall have $v' = 2$, if v remain as before; so that in this case the volume is doubled.

When p' is equal to p, the elastic force of the vapour entirely destroys the effect of the pressure it sustains from the air; and as this is constant during the whole time of the dilatation, because of the new vapour which is continually generated, the dilatation has no limit; and this is what is indicated by the formula in which the value of v' becomes then $\frac{vp}{0}$, an expression obviously denoting an infinite quantity.

313. The preceding representation leads us to two consequences: first, that in the union of a vapour with a gas, the elasticity of the mixture is the sum of the elasticities which the composants would have had, if each of them occupied the space filled by the mixture. For the

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(*f*) The juvenile reader may easily convince himself that these two values of v' are identical though under different shapes, by converting the mixed quantity $v + \frac{vp'}{p - p'}$ into its equivalent improper fraction $\frac{vp - vp' + vp'}{p - p'}$, the two last terms in the numerator of which, having contrary signs, destroy each other, and leave $\frac{vp}{p - p'}$, for the real value of v'. Tr.

elasticity of the mixture is P, which is equal to the elasticity $P-P'$ of the gas, + the elasticity P' of the vapour.

314. From the second inference we learn, that the volume of the mixture, after its dilatation, is the sum of the volumes which the composant parts would have occupied separately, under the primitive pressure sustained by the gas. For, in the formula $V' = V + \frac{VP'}{P-P'}$, V represents the primitive volume of the air. Let v be the volume into which the vapour would be contracted by the pressure P: so shall we have $v : V' :: P' : P$; or, $v : \frac{VP}{P-P'} :: P' : P$. Whence we find $v = \frac{VP'}{P-P'}$, a quantity which when added to V, gives the total volume.

315. These results constitute a curious addition to the theory of elastic fluids: but the way in which our author has considered this subject is not sheltered from difficulties. He conceives that when a vapour, such as aqueous vapour, is mixed for example with atmospheric air, the moleculæ of each fluid repel one another mutually, without either of them exercising any action upon the particles of the other fluid. Thus, at the very instant of the mixture, the elasticity of the vapour disburthens the air of a part of the pressure which it sustained. This air therefore is dilated by the excess of its elastic force, until the part of it which remains, together with the elasticity of the vapour, are in equilibrio with the pressure. In this state of things the moleculæ of each fluid are so interposed between those of the other, that if we suppress, mentally, those of the vapour, and suppose that the air has only to support the pressure $P-P'$, there will be no change produced in the disposition of its moleculæ. The same thing will obtain with regard to the vapour, if it be supposed that the air is evanescent. These are two parts of the same system which act independently one of another, like two distinct series of little springs inserted one kind between the other, so that

those of each kind might exercise their force separately. If any particle of one of the fluids experiences a resistance on the part of the moleculæ of the other, it could only be a resistance of percussion, so to speak, a resistance similar to that which obtains in the collision of solid bodies, and which, of course, can only exist accidentally, in consequence of contact.

316. Many objections drawn from the principles of chemistry have been opposed to this doctrine; and no person has better defended in this point the laws of affinity than Bertholet, in that elegant work in which he has presented the theory of this force in a manner so novel and so worthy of his genius *. But, that we may confine ourselves here to a single consideration drawn from physics, we shall observe that the view of the subject taken by the celebrated English philosopher does not appear to accord with the hydrostatical principle, that the pressure to which a fluid is subjected is equally distributed in all directions, so that each point of the fluid sustains the whole entirely. It follows that in the hypothesis of Dalton, each of the composants, resisting only a part of the pressure, would yield to its superabundant force, and the vapour would be reduced to water (*g*).

To place things in their true point of view, we shall imagine, instead of the vapour which introduces itself into the air, a fresh quantity of that air possessing the same degree of elasticity as the vapour. This new air will separate, by its elastic force, the moleculæ of the

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* Essai de Statique Chimique, part. I. p. 485, et seq.

(*g*) Mr. John Gough of Middleshaw, near Kendal, (a gentleman who, although he is deprived of sight, possesses great depth of mathematical and philosophical knowledge, as well as other most extraordinary acquirements), has objected to Mr. Dalton's theory as repugnant to the principles of the mechanical philosophy, and contradictory to some well established facts. Severa controversial papers on this topic, by Mr. Dalton and Mr. Gough, are published in the *Manchester Memoirs*, vol. I. New series. An abridgment of them is inserted in No. 5, of the *Retrospect of Philosophical &c. Discoveries.* Tr.

former, and the whole mass will assume a uniform density, such that this mass after its dilatation will be in equilibrio with the pressure which is equally distributed in every part. But, the vapour united with the air is in the same situation as that new quantity of air of which we have been speaking. It separates, in like manner, the particles of air between which it has introduced itself, and its own moleculæ adjust themselves to the degree of density requisite to make equilibrium with the pressure: the only difference consists in this, that the air which, as we have seen (296), exerts its affinity upon the water it raises by evaporation, continues to exercise it upon the vapour with which it is saturated; and the effect of this affinity is to prevent the vapour from yielding to the pressure, which would, otherwise, force that vapour to return to the liquid state.

317. Reasoning from the results which we have explained, and combining with them those obtained by Gay-Lussac, with respect to the dilatation of elastic fluid, a remarkable approximation has been obtained for the idea of which we are indebted to the illustrious Laplace. Saussure has found by a direct experiment, as we have already said (308), that the quantity of aqueous vapour contained in a cubic foot of air, at the temperature of 15° on the thermometer of 80 parts, is about 10 grains. But this vapour is here in the same state as if it occupied alone a space equal to a cubic foot under a pressure of 6 lines (307). Let us now enquire, from the theory of dilatation, what, according to this hypothesis, will be the weight of the same vapour.

It is known that at the temperature of 80°, and under a pressure of 28 inches (French), the vapour of water is about 1600 times lighter than liquid water. A cubic foot of water weighs 70 pounds ($62\frac{1}{2}$lbs. averd.); whence it follows that the weight of a cubic foot of aqueous vapour at 80° R, and under a pressure of 28 inches, is equal to $\frac{70}{1600}$ lbs. Let us suppose that this quantity of vapour, by remaining always at a temperature of 80° R, sustains only a pressure of 6 lines: its new volume will be to the primitive volume in the inverse ratio of the pressures, that is to say, as 28 inches is to 6 lines, or as 56 is to unity: therefore, after the dilatation a cubic foot of this vapour will weigh only $\frac{70 \text{ lbs.}}{56 \times 1600}$, or $\frac{1}{1280}$ of a pound.

But this volume being calculated upon the supposition of a temperature of 80° R, we must reduce it to what it would be at a temperature of 15° R, which is that possessed by the aqueous vapour in Saussure's experiment. Now, Gay-Lussac has found that the gases are dilated about the $\frac{80}{213}$ of their volume (288), in passing from the temperature of thawing ice to that of boiling water; whence it follows that if we will content ourselves with a moderate approximation, we may suppose that the dilatation is $\frac{1}{213}$ of the volume, for each degree of heat. Consequently the density of a quantity of vapour whose temperature is 80° R, is to that of the same quantity at 15° R, as $1 + \frac{80}{213}$ to $1 + \frac{15}{213}$, or as 293 to 228. Since, therefore, with equal volumes the weights are as the densities, the weight of a cubic foot of vapour at 15° R, is $\frac{293 \text{ lbs.}}{228 \times 1280}$, or about 9·3 grains*; a result differing but little from that of Saussure: such is the advantage of experiments even when insulated, if they are accurately performed.

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* See in the *Bulletin des Sciences de la Societé Philomath.*, ventôse an 11, p. 189, an article by Biot, in which that learned mathematician, after having explained the results of Dalton's theory, gives the calculus relative to the approximation we have now been considering.

On Winds and Aqueous Meteors.

318. The atmosphere is continually solicited by the action of various causes, such as heat, vapours, &c., which acting unequally upon different parts, tends to make a change in the ratio of their specific gravity, and that of their elasticity; and these are, in general, the causes whence *winds* originate, by displacing a portion of air, and communicating to it a progressive motion. Winds are very justly denoted by the apellation *currents of air*.

319. The intensity of the force of the wind varies between widely extended limits, from the slight agitation which produces the zephyr up to that impetuous motion whence hurricanes result. M. Kraaft, who has made observations on the velocity of the wind at Petersburgh, says that he once found it 109 feet (35·4 metres), and another time 120 feet (39 metres) per second* (*h*).

320. Winds follow an infinitude of different directions, some oblique, others parallel to the horizon. But in the usual estimation of the direction of the wind, we limit the

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* Encyclop. Method. Marine, t. III, 2d part, pa. 873.

(*h*) The most decisive circumstance tending to shew the great velocity of brisk winds, is that of the rapid passage of the celebrated aëronaut M. Garnerin, from London to Colchester. On the 30th of June 1802, the wind being strong though not impetuous, M. Garnerin and another gentleman ascended with an inflammable air balloon from Ranelagh Gardens, on the southwest of London, between 4 and 5 o'clock in the afternoon; and in exactly three quarters of an hour they descended near the sea, at the distance of 4 miles from Colchester. The distance of the places of ascent and descent is at least 60 miles; so that, allowing no time for the elevation and depression of the balloon, but, supposing the whole period occupied in transferring it in a path nearly parallel to the earth's surface, its velocity must have been at the rate of 80 miles per hour. If, therefore, the wind moved no faster than the balloon, its velocity was then 80 miles per hour, or 117⅓ feet per second; a celerity but little less than the greatest assigned by Kraaft: and hence it is probable, that the velocity of very impetuous winds is not less than 130 or 140 feet per second. Tr.

consideration to the point of the horizon from whence it appears to proceed in order to reach the observer, who is regarded as being above the centre of the circle; and the circumference of that circle is imagined to be divided into 32 equal parts by 16 diameters, which gives, estimating from the circumference to the centre, 32 directions, which are named *points of the compass*, or *rhumbs*; the whole is called by the French *la rose des vents*, by the English *the compass card.* See fig. 30. pl. V.

One of the diameters, which coincides with the meridian at the place of the observer, points out the North by one of its extremities, and the South by the opposite one. The diameter which intersects the preceding at right angles indicates the East on one side, and the West on the other. These four points are named in general *Cardinal points.*

The names of the intermediate points between the cardinal points, participate of the names of those points, combined two by two, three by three, without addition, or three by three with the interposition of the fraction $\frac{1}{4}$, in proportion as the corresponding points subdivided, into parts always smaller, the space comprised between two neighbouring cardinal points. This nomenclature is founded upon the following principles: 1st. In the binary combinations, as North-East, South-East, &c. the name of North, or that of South, always retains the first place. 2d. Every ternary combination, without addition, such as North-north-east, East-north-east, &c. is given by the name of the nearest cardinal point, followed by the nearest binary combination. 3d. With regard to the ternary combinations, with the addition of the fraction $\frac{1}{4}$, there is a distinction to make. If the point to which the combination answers is near a cardinal point, the combination is formed of the name of that point, and then of the fraction $\frac{1}{4}$, to which the name of the nearest binary combination is added. Thus, North-quarter-of-North-east, signifies that the point indicated by that combination is near the North, and that its distance from the North is the quarter of that which separates it from the North-east. If, on the contrary, the point to which the combination appertains is near another point answering to a binary combination, which is the case with the point North-east-a-quarter-North, the combination is formed of the name of that binary combination, and of the fraction $\frac{1}{4}$, with the name of the nearest cardinal point; whence it is evident that this mode of combination is the inverse of the preceding. Among the variable directions of the infinitude of different winds, the thirty-two now mentioned have been chosen as a kind of limit to which all the others are referred *(i)*.

321. Winds, considered in relation to their duration, to their returns, and other similar circumstances, are divided into general, periodical, and irregular winds.

The general winds or those whose action is continual, and follows one constant direction, predominate between the tropics, and rarely beyond them. Such is the East-wind, of which we have given the most natural

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(*i*) The only differences between the nomenclature of the compass-card, as described by M. Haüy, and that which now prevails in England, are, 1st. In cases where the French place the fraction $\frac{1}{4}$ between the name of a cardinal point and a binary combination, the English place the preposition *by* between the name of the cardinal point, and the last name of that binary combination: thus, instead of *Nord quart de Nord-East*, we say, *North by East*. 2dly. In cases where the French place the fraction after the binary combination, we subtitute the word *by* for the fraction $\frac{1}{4}$: thus, instead of *Nord-est quart de Nord*, we say *North-east-by-North*. Our mariners likewise divide each of the 32 points into quarters, which they denote by fractions, as N $\frac{1}{4}$ E, N $\frac{1}{2}$ E, N $\frac{3}{4}$ E, N *b* E, N *b* E $\frac{1}{4}$ E, N *b* E $\frac{1}{2}$ E, &c. ; as may be seen under the article *Compass* in Hutton's Dictionary, or in Table 9 at the end of Mackay's Navigation : but these subdivisions are too minute to be recommended. Indeed, in our opinion, nothing but the force of custom will authorise the farther use of even the 32 points; since their subdivisions do not well accord with either the common or decimal division of the quadrant. Instead of the usual characters, such as N 50° E, N 34° W, &c. meaning 50° from the north towards the east, 34° from the north towards the west, &c. would answer every purpose, and would be much more ready in computation. But this is a point which need not here be dwelt upon. TR.

explication, making it to depend upon the rarefaction of the air produced by the solar heat (280). The Periodical winds, named also *Trade-winds* and *Monsoons*, blow constantly for several months, and are usually followed by contrary winds of an equal duration.

The irregular winds are those which blow from different quarters in the same country, without conforming to any period or any determinate duration: these are the most ordinary winds in temperate climates. It very commonly happens that two or three of these winds blow at the same time, one above another, in different directions *: and sometimes a violent wind is experienced upon a mountain at the foot of which the air is tranquil; at others, the contrary circumstance takes place †.

322. The accidents sometimes occasioned by the violence of winds, are amply compensated by the advantages we derive from these currents of air. They are these, which in great cities, cause a salubrious air to succeed an air vitiated by noxious emanations. They transfer from place to place the clouds that are destined to scatter over the earth those rains which render it fertile: they are the vehicles of a multitude of seeds, which being provided with wings or down, are wafted to all parts during the autumn, and keep up a constant circulation of vegetable riches between different soils *(k)*.

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* Muschenbroek, Essai de Physique, t. II. p. 879.

† Deluc, Recherches sur les Modific. de l'Atmosphere, No. 730.

(*k*) M. Haüy, probably considering the most plausible theories of winds as almost altogether hypothetical, has said but little on this subject. And indeed, when we reflect attentively upon the nature of winds in general, considering all the causes which disturb the equilibrium of the atmosphere, the great mobility due to its fluidity and its elasticity, the influence of heat and cold upon the latter, the immense quantity of vapour with which it is charged and discharged alternately, the mutual effect of contiguous air and water in motion, the varied attractions of the sun and moon, upon the aerial fluid, and finally the changes produced by the earth's

323. Human industry has found in the force of the winds a most powerful mover, whose impulsion upon the sails of ships directs those floating edifices towards places where nature abounds in productions valuable in commerce, or useful to the progress of natural history. Before the invention of our mills, what strength of arms and repeated efforts were employed in grinding the corn from which we derive our most solid nutriment! The action of the wind supplies all this, by exerting itself upon four sails which perform the office of levers, and whose surfaces, inclined two and two in a contrary direction, receive, by means of this ingenious disposition, such motions as conspire to produce the rotation of the axis upon which the sails are fixed *.

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rotation in the velocity of the atmospherical moleculæ at different parallels of latitude; we shall no longer be astonished at the inconstancy and variety which infringe upon the regularity of some of our winds, or at the extreme difficulty of reducing the whole to laws wearing the semblance of certainty. The most ingenious theories of the periodical winds we recollect, are those of Mr. Hadley, first proposed in *Phil. Trans.* vol. xxxix. p. 58, and lately revised by Mr. Dalton in his *Meteorological Essays*,—and of Dr. Halley, first published in *Phil. Transac.* vol. xvi. p. 153, and recently defended by Dr. Kirwan, in his paper *On the Variations of the Atmosphere.* In the latter mentioned paper Kirwan has given some interesting information relative to variable winds, as westerly, easterly, southerly, northerly, and opposite concomitant winds; also relative to the succession of winds, and the *Scirocco.* See likewise the *Phil. Magazine*, No. 60. Some curious facts respecting winds, and waves on the surface of the sea, are related by Mr. Horsburgh in the *Phil. Journal.* No. 60. Tr.

* Let AB (fig. 31.) the projection of the anterior surface of the mill, mn that one of the sails or vanes which we will suppose to be arrived at the highest point of its rotation, $m'n'$ that of the sail opposite to the preceding, and which is therefore at the lowest point of its rotation; let, moreover, fg be the direction of the wind, to which the surface A B, whose surface can be varied at pleasure, is always perpendicular. The force of the wind, which acts obliquely upon the sail mn, according to the line or, is resolvable into two other forces, of which the one, represented by os, and parallel to mn, produces no part of the effect; and the other, represented by ot, and perpendicular to mn, impels the sail from the left to the right, or from A towards B. Adopting similar reasoning with respect to the inferior vane $m'n'$, we shall hence conclude that the force $o't'$, which performs the same

324. We have given the name of *meteors* to all bodies which, either suspended or in motion in our atmosphere, become there the agents of some phenomenon. We only propose to consider here those which owe their origin to the aqueous fluid.

325. When the vapours diffused through the air are separated from that fluid by the effect of refrigeration or of some other cause, they approach each other, and tend towards their return to the liquid state; and when their specific gravity which becomes augmented, is alone nearly equal to that of the air, they remain suspended in the atmosphere, under the form of fogs, or of clouds. But if their condensation becomes so great that the drops of rain which result from it can no longer be sustained by the air, that circumstance determines their precipitation, which, in the ordinary cases, produces a rain more or less abundant.

326. Snow is occasioned by a similar precipitation, in which the water is reduced to very small globules which

function as qt, acts to make the vane $m'n'$ move from right to left, or from B towards A. But this action concurs with that which is exerted upon the superior vane, to produce the same motion of rotation; instead of which, if the inferior sail were disposed in the same plane, as that above, the two motions would destroy each other. What has been here said of the actions relative to the highest position of the sails, applies equally to all the other positions.

It is easy to see that the sails would remain immoveable, if mn and $m'n'$ being parallel to A B, received the impulsion of the wind directly; or if, being perpendicular to A B, they had the same direction as the wind. There is, therefore, between these two limits, an oblique position under which the force of the wind is a *maximum*; and mathematicians have demonstrated that the *maximum* obtains when the angle orn which the direction of the wind makes with the surface of the sail, is $54^\circ\ 44'\ 8''$ (*l*).

(*l*) Our author's view of this subject is meant to be popular, and therefore does not enter into minutiæ: yet it may not be improper to add, that, when the sails are to produce a maximum effect, the whole of one sail is not to be confined to the same plane; but ought to be turned more towards the wind in the extreme parts where the motion is swiftest, than in the parts nearer to the axis of motion. On this subject the reader may consult Maclaurin's Fluxions, vol. i. Gregory's Mechanics, vol. i. and the additions in the 2d vol. of Brewster's Ferguson. Tr.

are congealed in the midst of a cold air, and, several uniting together during their fall, arrive at the earth under the form of a species of star of six rays (204), if their crystallisation be accomplished in a calm air, or, in the shape of irregular flakes, if the agitation of the atmosphere cause the crystals to strike against one another, and thus to become united in groups.

327. Hail differs from snow in many circumstances, of which one of the most remarkable is the very epoch of its formation, which only takes place during hot seasons. It arises from a shower of water whose drops are congealed by the effect of the very cold temperature which then reigns in the higher regions of the atmosphere. These globules of ice then present to the aqueous moleculæ which they meet with in their path a kind of nuclei, about which those moleculæ arrange themselves, and become congealed in successive concentric shells, so that the volume of each globule becomes augmented. Hailstones, however, are rarely spherical; their form, on the contrary, commonly presents cavities and angular parts. Some of them appear to be an assemblage of many stones of a smaller volume, collected together during their descent.

328. Another phenomenon, which we should greatly admire if it were less formidable, is that of the water-spout. It proceeds from a cloud which exhibits itself in ordinary cases under the form of an inverted cone, whose base adheres to the other clouds, to which the cone is, as it were, suspended. When the water-spout is formed above the sea, the water corresponding to it is elevated and forms a second cone, whose axis is in the same direction as that of the superior cone. The water which is precipitated from all parts of the water-spout, and with which is sometimes combined an abundant hail, is driven along by impetuous winds which outrageously whirl the whole about. The ravages occasioned by this meteor are very terrible. It tears up

by the roots the strongest trees, and throws them far from the places where they grew. If it pass over a city or town, it overthrows roofs, chimnies, or even the walls of the houses, and sometimes tears up the iron bars that support weathercocks, &c. The mariners, when they perceive a waterspout, exert every effort to sail away from it, under the apprehension that if it were to fall upon the vessel, it would sink it in an instant. This meteor is much more rare upon land than at sea; but there it shews itself with sufficient frequency during great heats, and after a long calm*.

329. The variations of the atmosphere, by augmenting or diminishing the pressure exerted by the air upon the mercury of the barometer, causes the column of that liquid to lengthen and contract, in such manner that the quantity of the pressure in question is indicated at every instant by the number that answers to the height of the mercury: and since it pretty frequently happens that the barometer falls when the air is much agitated, or at the time when it is likely to rain; while on the contrary it rises at the approach of calm and serene weather, there are joined to certain degrees of the scale, such indications of the state of the sky, &c., as the height at which the mercury then stands seems most commonly to presage. But observation proves that fine weather and rain have not a constant and regular influence upon the variations of the barometer, which have no exact ratio except with the pressures; hence it may be said that the arithmetic of this instrument is more certain than its language.

Even on the supposition that the predictions of the barometer always accorded with the facts, it would be requisite that we should know how to apply this accordance in a satisfactory manner. But notwithstanding the ability of the philosophers who have devoted

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* Encyclop. Method., Marine, vol. iii., part 2. p. 791.

their attention to this subject, and generally to all that is connected with the variations of the atmosphere, it seems to us that the theory which has been given still leaves much to be desired. We have, however, some principles solidly established whose connection with the object of this theory encourages us to hope that they will some time be advantageously employed in the required developement. Such are those which result from the experiments of Le Roy, Gay-Lussac, and Dalton. It is by combining these principles with a series of observations on the state of the atmosphere, that we may be able to remove the numerous difficulties that present themselves, to comprehend the diversity of phenomena the aggregate of which should be embraced by the theory, and that of the causes which so frequently combine in the production of a single phenomenon.

On the Origin of Fountains.

330. Evaporation has furnished the true explication of another circumstance which had long embarrassed philosophers. It is seen that brooks and rivers run continually from their sources towards the sea, and yet that those sources are not dried up. The sea receives on every side the tributes of these different waters, and yet the sea does not overflow. Hence it has been inferred that the waters must return from the seas to the fountains, and that nature has established between the former and the latter an uninterrupted communication. But by what channel is this return accomplished? Where are the conduits which carry back the waters of the sea to the sources of fountains? How do they lose their saltness in their passage? This was the point where the difficulty resided; and to resolve it recourse has been had to different hypotheses more specious than solid.

Some philosophers, adopting the idea of Descartes, have thought that the waters of the seas travelled through subterranean canals to deposit themselves in great caverns situated at the base of mountains; where by vaporisation they become freed from their salt, and after being elevated to the upper parts of the cavity, they are condensed by cooling, and thence flow to the origin of brooks and rivers. This it will be seen is a true distillation similar to that which is performed in the laboratories of the chemists.

According to others, the waters of the sea, impelled by the action of the flowing tide, may introduce themselves into the earth by a great number of fissures, in which they undergo a filtration that takes from them their salt. This kind of canals whose ramifications are extended in every direction and every part, may thus conduct the waters to the places where their junction forms springs.

If we estimate the value of such hypotheses according to the notions of a sound philosophy, we shall easily conceive that to admit into nature these alembics and these filtres would be to lend her the means of art, and then constrain her to copy them; though this would in many cases be to present her with a model not to be imitated. We shall also conclude, after all, that we need not seek for any other origin of fountains than that of rains themselves; and the following is what observation and reason equally dictate with regard to this object.

331. Water is raised from all parts into the atmosphere by evaporation. Sea water deposits its salt, in proportion as it yields to the attraction of the air. A part of the dews and showers which arise from these waters fall upon the summits of mountains: indeed those summits appear to act by affinity upon the clouds, and to detain them in their neighbourhood. It has been observed that a cloud which met with a peaked

hill in its passage, gradually disappeared as its different parts approached to contact. The waters would in that case descend gradually, as in a filter, into the earth composing the hill, until they reached an impermeable bed; and from thence they would issue at different places on the sides and at the foot of the hill, where the reservoir into which they run would shew itself openly.

In primitive mountains the waters flow along hard stones, which compose, as it were, the scaffolding of those great masses, and from the junction of such streams torrents are formed. The secondary mountains, whose constituent matter is softer, and in a manner spongy, permit the waters to penetrate to a greater depth, where they are arrested by a stratum of clay whose slope they slide along, till they meet with joints in the neighbouring strata through which they discharge themselves. Those which do not appear at the surface continue to run along in the bosom of the earth, whence they are drawn up by men to the mouths of wells sunk near their habitations.

332. But do we not impute too much to evaporation when we suppose that it alone can furnish the immense quantity necessary to supply so many springs; especially when we take into the account that which is lost in brooks and rivers, which serves for the drink of animals, or which is absorbed by plants? Mariotte, in his Treatise on the Motion of Water, has discussed this question with his usual exactness, by comparing the quantity of rain water which fell at Paris and its environs in the compass of a mean year, with that which passed, during the same time, under the *Pont-Royal:* the result of his observations and calculations was, that the water which falls in rain, &c., so far exceeds the quantity requisite to maintain the course of rivers, and to fill the pools, that we must suppose the remainder employed with an excessive profusion (if we may

be allowed such language), in supplying the necessities of vegetation, and other particular sources of consumption. Thus the solution of the difficulty seems to furnish a new objection, of a directly contrary kind (*m*).

(*m*) Dr. Halley deduced a nearly similar theory of the origin of springs from his experiments on evaporation, whose result is contained in the following articles: 1. That water salted to about the same degree as sea-water, and exposed to a heat equal to that of a summer's day, did, from a circular surface of about 8 inches diameter, evaporate at the rate of 6 ounces in 24 hours: whence by a calculus he finds that, in such circumstances, the water evaporates 1-10th of an inch deep in 12 hours: which quantity, he observes, will be found abundantly sufficient to furnish all the rains, springs, dews, &c., even without taking the wind and other causes of evaporation into the account. By this experiment, every 10 square inches of surface of the water yield in vapour *per diem* a cubic inch of water: and each square foot half a wine pint; every space of 4 feet square, a gallon; a mile square, 6914 tuns; and a square degree, of 69 English miles, will evaporate 33 millions of tuns a day; and the whole Mediterranean, computed to contain 160 square degrees, at least 5280 millions of tuns each day. Philos. Trans. vol. xvi. or New Abridgment, vol. iii. pa. 387.

In the next volume of the Transactions (or Abridg. vol. iii. pa. 427) the Doctor applies these facts to the circulation of the water and the origin of springs in the following manner. Those vapours that are raised copiously in the sea, and carried by the winds over the low lands to the ridges of mountains, as the Alps, the Pyrenees, Mount Caucasus, the Montes Lunæ, &c., are there compelled by the stream of the air to mount up with it to the tops of the mountains, where the water presently precipitates, gleeting down by the crevices of the stone; and part of the vapour entering into the caverns of the hills, they are collected into the basins of stone they find there, which being once filled, all the overplus of water that comes thither runs over by the lowest place, and breaking out by the sides of the hills forms single springs; many of these running down by the valleys or guts between the ridges of hills, and uniting, form little rivulets or brooks; many of these again meeting in one common valley, and reaching the plains, become less rapid and form a river; and many of these being united in one common channel, make such streams as the Rhine, the Rhone, and the Danube; which latter could hardly be supposed to be supplied from vapour, did we not consider how vast a tract of ground that river drains, and that it is the aggregate of all those springs which break out on the south side of the Carpathian mountains, and on the north side of the immense ridge of the Alps.

Thus then is one part of the vapours blown upon the land, returned by the rivers into the sea from whence they came. Another part, by the cool of the night, falls in dews, or else in rains, again into the sea, before it

The explication we have just given, refers these operations of nature to her ordinary simplicity. The atmospheric air, by its own action alone, incessantly attracts to it the waters that are diffused over the surface of the globe, and after having served them for a vehicle, it permits them to be precipitated here and there, it yields back all which is required, to the thirsty fields and meadows whose drought it removes, to the springs and sources of rivers which it feeds, and to the ocean whose loss it repairs.

333. The region in which all the different phenomena occasioned by evaporation take place, does not extend to a great height in the atmosphere. According to Muschenbroek the most elevated clouds seldom rise above the summits of our highest mountains. Attempts have been made to determine the altitude of the atmosphere itself, which would be very easy if the air had throughout the same density as it has at the earth's surface. It would suffice in that case to take the ratio between the densities of mercury and air, or between their specific gravities, and to multiply that ratio by 28 French or 29·9 English inches, which would give

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reaches the land; which is by much the greatest part of the whole vapour because of the extent of the ocean, which the motion of the winds does not traverse in a very long space of time. And this is the reason why the rivers do not return so much into the Mediterranean as is extracted in vapour. A third part falls on the lower lands, and is the pabulum of plants; where yet it does not rest, but is again exhaled in vapour, and is either carried by the winds to the sea, to fall in rain or dew there, or else to the mountains, to be there turned into springs; and though this does not immediately happen, yet after several vicissitudes, of rising in vapour and falling in rain or dews, each particle of the water is at length returned to the sea from whence it came.

This hypothesis the doctor founded upon his personal observation while at St. Helena, where in the night time, on the tops of hills, about 800 yards above the sea, there was so strange a condensation, or rather precipitation of the vapours, that it was a great impediment to his celestial observations: for in the clear sky the dew would fall so fast as to cover his glasses with little drops, so that he was necessitated to wipe them each half quarter of an hour; and the paper on which he registered his remarks would immediately be so wet with the dew that it would not bear ink. Tr.

about 7815 metres, or $5\frac{1}{4}$ miles for the height required. But this determination deviates very widely from the truth, because of the diminution undergone by the density of the air in proportion as it is farther from the earth. Lahire has endeavoured to deduce the height of the atmosphere from the duration of the crepusculum or twilight. It is known that we begin to perceive the rays of the sun, when that luminary is still depressed 18 degrees below the horizon. Now those rays could not then come to a spectator to whom the horizon in question was related, otherwise than by being first refracted on penetrating the atmosphere, and afterwards being reflected by its concavity, from whence they are sent back towards the observer. There is, therefore, a certain height which the atmosphere ought to have, so that the reflection which produces the crepusculum shall commence when the sun is 18 degrees beneath the horizon; and Lahire on computing this height found it to be nearly 16 leagues. This result, however (admitting the accuracy of the calculation), merely proves that at the distance of 16 leagues the effect of the atmosphere to reflect the light is still perceptible; so that we are only certain that the atmosphere extends at least so far, without being able to assign its ultimate limit.

On Air-Balloons.

334. After having explained the knowledge hitherto acquired relative to the different states of the air, we cannot refrain from giving some details respecting a discovery which may enable us to collect new truths on this subject, and which, besides, is in many points connected with philosophy. What we allude to is the invention of air-balloons, by which Mongolfier has given a lasting celebrity to his name.

The idea of a voyage undertaken by man in the midst of the air, premised a spectacle so imposing and so calculated to excite admiration, that we may easily conceive the probability of our meeting more than once with men sufficiently hardy to attempt to realise it. The flight of birds, on the birth of this sentiment of rivalship, seemed to offer the model of the mechanism which might serve for the execution of the project. But in the first place, a bird derives facility in executing the various motions of its flight from the conformation of its body, and from the position and structure of its wings composed of feathers of very light structure, being in fact hollow tubes: moreover, the great muscular force with which they have been provided by the Author of Nature gives them the advantage of striking the air with such power and rapidity, as to raise themselves at will, to dart forward, or to hover over the same place. In man, on the contrary, the muscular force, far from compensating the disadvantage of the weight, is greatly inferior to what it ought to be, all other things being equal, to put it in a state to act upon the air, with such an excess of velocity, that it may find a fulcrum in that fluid so moveable and so ready to yield. Hence the unsuccessful trials of all those who have aspired to the practice of an art, which they were compelled to resign to the fabulous heroes of antiquity.

335. We may aim at the same object in another way, by substituting for the mechanism of flying that of navigation. During the last century, Lana and Gallien, confining themselves to simple speculations, proposed two different means of accomplishing this second object. Lana composed his apparatus of four hollow copper globes, from which he had exhausted the air, and which being at once very spacious and very thin, would become capable, by their excess of levity, of raising a man with his support. But many

philosophers have refuted that notion, by objecting that such globes could not fail to be rent by the pressure of the atmosphere.

Gallien started an idea which at first appeared more plausible in itself, and which consisted in causing to float in the atmosphere a large vessel occupied by an air relatively lighter than that which supported it. The difficulty would have been in putting this principle into execution; but as Gallien did not pretend to offer his reader more than a philosophical recreation, a method of performing an ideal voyage, he did not trouble himself with prescribing the means, but merely contended for their possibility in nature. In consequence he imagined his vessel to be as large as a city, and capable of containing an army with all appropriate ordnance and ammunition, and provisions for a long voyage. He then supposed it transported into the atmosphere to such a height that the included air may be as light again as that above which it would float. But, to whatever height the sides of the vessel might be elevated, the air which was introduced therein would be compressed by its own weight in the same ratio as the surrounding air; and it is easy to conceive that from that time the vessel could not sustain itself a single instant in the midst of the atmosphere.

336. Thus there had been nothing produced respecting the art of rising in the air, except unfruitful attempts, and false and romantic speculations, when in 1782, Mongolfier, having reflected upon the phenomena presented by clouds which sustain themselves and float in the atmosphere, conceived the idea of giving very light coverings or wrappers to factitious clouds composed of vapours produced by the combustion of various substances. He thought that these vapours would, when mixed with the air rarified by the heat within the respective envelopes or bags, form with them a whole specifically lighter than the surrounding air,

Some attempts which he made privately with his brother having had a complete success, they repeated their experiments at Annonay the following year, in presence of a great number of spectators; when they made a kind of large bag of linen cloth lined with paper, and at first unformed, covered with plaits, and hanging down by its own weight, to become swoln and shaped by the action of heat, and afterwards to rise in the form of a balloon of 110 feet in circumference, and indeed to ascend to the height of 1000 toises.

It is well known that after this the experiment was frequently repeated at Paris, and that the machine served to elevate men who themselves kept up the fire in a chafing-dish or small grate properly suspended under the orifice of the balloon. In the first attempts the machine was retained by cords which would permit it to ascend to a certain height. But at length Pilatre des Rosiers and D'Arlandes, consigning themselves to the balloon when left to itself, passed over a space of near four thousand toises in seventeen minutes, and thus furnished the interesting spectacle of the first voyage made by man through the air.

Mongolfier in his experiments burnt animal substances with straw to inflate the balloon; and he believed that the ascent of the machine was partly owing to the presence of a particular gas, composed of different principles that had been developed in the combustion. But it is since proved that this effect proceeded solely from the rarefaction of the air contained in the balloon.

337. Soon after the report of the experiment at Annonay, Charles proposed to substitute for the dilated air, hydrogenous gas, which in the greatest state of purity it has hitherto been obtained is about thirteen times lighter than air. He only needed to find a covering that would be impermeable to this gas, and in which it might be imprisoned. This process was

more expensive, but at the same time less dangerous and more simple than the former; the balloon was sufficient in itself, and its volume as well as its weight was found sensibly diminished. Among the different substances of which the coverings might be constituted, Charles preferred taffeta varnished with elastic gum, which is formed of the thick sap *(n)* of an American tree wherein incisions are made to promote the discharge. He dissolved this gum in oil of turpentine before he applied it to the taffeta. He launched from the Champ-de-Mars a globe constructed by this process, of about 12 feet in diameter: this globe rose in two minutes nearly 5000 toises; it sustained itself about three quarters of an hour in the air, and then fell almost four leagues from Paris.

Some time after Charles and Robert carried in a boat suspended to another balloon of the same kind, and 26 feet in diameter, passed over a space of 9 leagues before they descended; and shortly, Charles remaining alone in the boat, by a new flight worthy of his zeal and his courage, rose in the twinkling of an eye to a height of near seventeen hundred toises, as if he went, in the name of philosophers, to take possession of the region of meteors.

(*n*) The elastic gum here mentioned is now well known under the names *Caoutchouc*, and *Indian Rubber*. The first regular account of this substance we have met with was sent to the French Academy in 1736, by M. Condamine, one of the Academicians who had been sent the preceding year to South America to measure a degree of the meridian. He informed the academy that in the province of Esmeraldas, in Brazil, there grew a tree called *hhevé* by the natives; that from this tree there grew a milky juice, which, when inspissated, was caoutchouc. It is now known that there are at least two trees in South America, from which caoutchouc may be obtained; the hævea caoutchouc, and the jatropha clastica: and it may probably be extracted from other species of hævea and jatropha, as well as from several trees of a nearly similar nature growing in the East Indies. The specific gravity of caoutchouc is 933·5, that of rain water being 1000. This substance is improperly denominated elastic *gum*; for it is inflammable, insoluble in water, but soluble in ether, oils, and alcohol; properties which characterise not gums, but *resins*. Tr.

In proportion as a balloon of this kind rises higher in the aërial regions whose density diminishes progressively, the gas being less compressed, makes an effort to expand, which may occasion the rupture of the balloon. This accident is prevented by adapting to the top of the balloon a valve, which the aëronaut has the power of opening, to permit the escape of a part of the gas, when its dilatation has attained its limit. We may even moderate the resistance of the valve, so that it shall be less than that of the cloth; and in this case the valve will open of itself to give issue to the gas.

The aëronauts were obliged to lose more of their gas when they wished to descend. They have proposed to enclose the balloon in another, occupied by atmospheric air; they could then expel at pleasure a portion of that air, or could furnish it *de novo*, by means of bellows adapted to the exterior balloon, which gave to any such aërial traveller a facility in elevating or lowering himself, as often as he wished, by retaining all his inflammable gas.

338. The use of balloons may lead to fresh knowledge, very interesting and important in the progress of physics. By their aid may be determined at what height the winds which blow in the inferior part of the atmosphere change their direction, when there are two opposite currents one above another: these observations would be especially valuable in the countries where trade-winds prevail. We might go and bring down the air from different elevations, which would be easy by taking up vessels filled with water, and then emptying that liquid to permit the entrance of the air of the respective region. The analysis would ascertain the ratio between the quantities of oxygen and azote, for each height (244 *note*). We might seek also to determine the law followed by the diminution of heat, in proportion as we rise higher; a knowledge very useful in the computation of astronomical refractions. Lastly, the study of the electricity of the air and of the different

meteors might be enriched by observations made at hand as it were, and even in the very region where those phenomena are produced *(o)*.

4. *On Air considered as the Vehicle of Sound.*

339. We have now to consider air as being the medium which transmits sound. We shall first exhibit the general phenomena of sonorous bodies: whence we shall pass to the comparison of appreciable sounds, from the relation between the number of vibrations corresponding to them; and finally, we shall deduce from observations relative to the effects of wind-instruments the most probable theory of the propagation of sound.

On Sound in general.

340. We may prove by a very simple experiment that air is the vehicle of sound. It consists in placing under the receiver of an air-pump a piece of clockwork adapted to produce sound in a bell, and which rests upon a bag stuffed with cotton or wool. A vacuum is produced, and then by means of a handle or stem which goes through the top of the receiver, a pressure is made upon a detent, which being thus unlocked, gives action to the machinery; the hammer is

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(o) It was not consistent with the nature of this work to give more than a brief sketch of the history and principles of Aerostation. Yet it might have been gratifying to see some little notice taken of the discoveries of Black and Cavendish, which were so near the point afterwards attained by Mongolfier. The English reader who wishes to acquaint himself more with this subject, may consult Gregory's Economy of Nature, the article Aerostation in Hutton's Mathematical Dictionary, or the same article in almost any of the recently published Encyclopædias. Tr.

then seen to strike the bell continually, but no sound is heard.

Hawksbee, to render this experiment still more decisive, placed the bell in a first receiver which remained full of air, and which was covered by a second receiver so disposed that a vacuum might be made between the two. Although, in this distribution of things, a sound was produced in the interior receiver when motion was communicated to th[illegible] yet the bell remained mute with regard to [illegible] he perceived no sound.

341. Hence it [illegible] an air rarefied to a certain degree, su[illegible]ch surrounds the apices of high mountain[illegible] to lose of its force; and if such a summit sta[illegible]e, the absence of echos will still further diminish th[illegible]tensity of sound. This is conformable to the observ[illegible]n of Saussure upon the top of Mont-Blanc, where, according to his account, the firing of a pistol caused no greater a report than a child's toy-gun made in a room.

342. On the other hand it is to be remarked, that sound acquired more force by passing through condensed air; and thus, the density remaining the same, the force of sound is augmented, as well as when the elasticity of air is augmented by means of heat.

343. It is the air, therefore, which conveys sound to the organs of hearing. But in what does that kind of modification undergone by air on occasion of a percussion impressed upon sonorous bodies consist? Let us take, for example, a cord of a stringed instrument, and suppose it struck as when played upon: immediately all the points of that cord will deviate more or less from the position which they occupied when the cord was at rest, according as they are more or less distant from the points where the cord is fixed; and the cord will go and return alternately on this side and that side its first situation, by a vibratory motion occasioned by its elasticity.

The particles of air contiguous to the different points of the cord assume motions similar to those of the respective points, that is, they move to and fro with them. Each particle communicates motion to that which is next to it, that to a third, and so on, till the moleculæ are reached which are in contact with the tympanum or drum of the ear. The air then acts upon that membrane, by communicating to it its own vibrations, which the drum transmits to the auditory nerve; and thence results the sensation of sound.

344. Let us now suppose that the sonorous body is a bell, as in the experiment which we have cited. We may conceive this bell to be formed of an infinitude of rings placed one above another from the base to the highest point: at the moment of the percussion each ring is compressed so as to assume an oval shape, whose greater axis is the perpendicular to the direction in which the stroke is made. The return of each ring to its first figure is succeeded by a new change of figure producing an oval posited with its axes contrary-wise to the former; and the two changes succeed one another thus, till the sound as well as the motion dies away. The vibrations of the moleculæ which compose each annulus, excite here also, in the neighbouring air, a small agitation which communicates itself from one particle to another, till the limit is attained where the sound ceases to be heard; and nearly the same may be said, duly regarding analogy, of all bodies shaken by means of percussion.

With respect to the degree to which the sound yielded by the bell corresponds, we must readily conceive that the rings situated nearer the base, having a greater circumference, tend to perform their vibrations more slowly, while the rings nearer the summit, whose circumferences are smaller, tend to produce vibrations oftener. Here therefore there will be established, nearly as in the compound pendulum, a compensation in virtue of which the vibrations become all reduced to an equal duration, which is a kind of medium between that which took place for the inferior rings, and that which measured the motion of the upper rings, if the former and the latter had been insulated.

345. An observation very easy to make, and which appears to us to merit being noticed, is that of the effect produced upon water by the vibrations of a drinking glass, filled with that liquid almost up to the top, while we move a moistened finger briskly round its rim, to excite a sound well known to all those who have amused themselves with the experiment. What has been remarked in such a case is this, the water turns round within the glass following the motion of the finger, and at the same time its surface is spread all over with minute whitish furrows, which succeed one another rapidly, proceeding from the periphery towards the centre; and if the motion be accelerated, the moleculæ of the water will spurt up on all sides about the glass and upon the hand of the observer. This experiment succeeds best with a goblet or foot-glass, which may be kept in a fixed position by leaning with the hand upon its base.

By using successively glasses of different magnitudes, it will be seen that the wrinkles become smaller, and take a more rapid motion, in proportion as the sound is more acute.

346. Sound may also be heard, but more weakly, through water, whether the sonorous body be plunged in that liquid, or the observer be immersed in it himself; which indicates, as we have before remarked (174) that water is compressible and elastic to a certain extent, although it have not yet been perceptibly compressed by direct experiments.

347. All solid bodies whose structure is such that a vibratory motion impressed upon some of their moleculæ will be communicated through their mass, are

in like manner capable of transmitting sound. A fact of this kind singular enough, and which the philosophers have not disdained to repeat after children, is that which takes place when, applying the ear to one of the ends of a long beam of timber, we hear distinctly the stroke made by the head of a pin upon the opposite extremity; while the same can scarcely be heard across the thickness of the piece. The reason of this difference is, that, in the first case the sound follows the direction of the longitudinal fibres, where the continuity of the parts is more perfect than in the transversal direction; and it is remarkable that those parts have so much elasticity, that the sound loses but little of its force in running over the space which they occupy.

348. Sound propagates itself on all sides in right lines, when obstacles hinder it; so that every point of a sonorous body may be considered as being the common summit of an infinitude of very slender cones of an indefinite length. Each of these cones constitute what is called a *sonorous ray:* as for the rest, we have only given here an unfinished sketch of the theory of the propagation of sound, to which we can return and fill up minuter parts, when we shall have exhibited those known circumstances which tend to furnish the developement.

349. Bodies which strike the air immediately, excite also in that fluid sonorous vibrations. Thus the air cracks under a whip which is violently agitated, and hisses under the stroke of a switch: it becomes equally capable of yielding sound, when itself moves with a certain velocity to strike a body, as when the wind blows against edifices, trees, and other bodies, opposed to its passage.

350. Sound employs a certain time to diffuse itself through the air, and is longer in arriving at the ear as that organ is farther from the sounding body. Philosophers have sought to determine, by experiment, the velocity with which sound is propagated; and to attain this

they have profited by the fact that the propagation of light is, on the contrary, instantaneous as to sense, at least in those distances where our measures extend. The explosion from cannon was well suited to give the results sought; nothing more was necessary than to estimate the time that elapsed between the moment when the flash of light indicated to the eye the departure of the sound, and that when the sound itself advertised the ear of its arrival. The uncertainty still hanging about the various experiments which had been made relative to this object, determined the French Academy of Sciences, in 1738, to undertake them anew; choosing a line of 14636 toises, situated between Monthlery and Montmartre.

They found that sound had a uniform velocity, by which it ran over about 173 toises or 337 metres in a second; so that it was merely weaker at a greater distance, but described successively equal spaces in equal times. The velocity appeared the same in rainy as in settled weaker; but the direction and force of the wind caused some variation. If the wind were directed perpendicularly to the line drawn from the sonorous body to the observer, the velocity of sound was notwithstanding the same as in a calm period; but if the direction of the wind concurred with that line, then, according as the wind moved the same way as the sound, or a contrary way, it was necessary to add the velocity of the wind to that of the sound, or to subtract it. Lastly, the force of sound did not cause any change in its velocity *(p)*.

(*p*) The uniform velocity of sound 1038 French feet per second, as determined by Cassini and the other French Academicians, is equivalent to 1107 English feet; which is about 35 less than the velocity 1142 assigned by Derham, and acquiesced in by Flamsteed and Halley. The Florentine Academy found the velocity 1148. Farther experiments are required, to determine which of these is nearest the truth; or whether the velocity does not vary in different times, places, and temperatures. Muschenbroek inclined to the latter opinion, and so have some later philosophers; yet Derham, whose experiments seem to have been conducted with great care, says "That in all weathers, whether the sky be clear and serene or

An acquaintance with the velocity of sound suggests an easy method of estimating nearly, by the flash and report of guns, distances which it is important to know at the instant, such as those from a besieged town, from a ship, from a seaport, &c.

Attempts have likewise been made to determine the velocity of sound, by the assistance of computation. But the theory gave for that velocity a quantity perceptibly smaller than what resulted from observation; and none of the hypotheses that were invented to account for this difference were satisfactory. Laplace, while reflecting upon a phenomenon the knowledge of which we owe to modern chemistry, has conceived the possibility of inferring the solution of the difficulty in question. It is known that air in proportion as it is condensed, developes a part of the latent heat which it contained, and which passes to the state of sensible heat; and on the contrary, when it is rarefied it absorbs a certain quantity of sensible heat, which becomes latent heat. Now, in the propagation of sound, the moleculæ of air experience successively little condensations and dilatations, similar to those of a spring which is alternately compressed and unbent. They develope, therefore, at the moment of the condensation, a small quantity of heat, which by raising their temperature augments their elastic force, whence there results an acceleration in the velocity of their vibratory motion. Afterwards when the expansion, which is a real dilatation, succeeds the compression, the small quantity of developed heat becomes again insensible; after which the same effects recur again, and so on: whence it appears that the propagation ought to be performed more rapidly than in the case of a uniform temperature.

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cloudy and turbid, whether it snows or rains, thunders or lightens, whether hot or cold, day or night, winter or summer, whether the mercury in the barometer rises or falls, in all changes of the atmosphere, *wind only excepted*, that the velocity of sound is neither greater nor less; only the sound will be more or less loud." Tr.

The manner in which Biot has applied the mathematical analysis to this idea, gives it a new air of truth. This able geometer has introduced into the formula that represents the velocity of sound, according to the ordinary theory, the expression for the augmentation of velocity that ought to be produced by heat; and as the quantities which enter this expression could not be determined without great difficulty by experiment, he proposed to himself the inverse problem, which consists in investigating from our established knowledge respecting the propagation of sound, what ought to be the small portion of heat rendered sensible by each condensation, and the augmentation of elasticity which is the consequence of it, so that the formula should accord with observation: he has found that the values to which the calculus leads exhibit nothing that is incompatible with the results of experiments made upon a large scale; which promises a direct solution of the problem, founded on the cause we have mentioned, when observation shall have furnished the requisite data (*q*).

(*q*) The common theorem for the space through which sound passes in the air, or indeed in any expansible substance, is $s = \sqrt{\frac{2ga}{d}}$, where g is the space through which a heavy body falls in a second, or any other time for which s the space is required, a the elasticity of the expansible fluid, which is assumed equal to the pressure it sustains from the atmosphere, and d the density of the expansible fluid; a may also be the height of the barometer, if the density of the mercury be considered as unity. This theorem gives about 960 English feet, for the distance to which sound is transmitted through the air in a second, while experiment gives 1142; the difference between these results M. Haüy endeavours to account for in the text.

Chladni and Jacquin of Vienna made about 10 years ago some experiments with a view to determine the sonorous properties of different gases, the results of which being curious may be stated here. By causing a small tin pipe, brought into contact with a cock in the neck of a bell glass, to be blown by gas contained in a bladder applied to the external aperture of the cock, these philosophers observed, that the sound was a semitone lower with azotic and oxygen gas than with atmospheric air; a third lower with carbonic acid gas; and nearly the same with nitrous gas: but,

351. When sound meets a body which opposes an obstacle to it, the particles of air which strike that body are reflected after the manner of elastic bodies, making their angle of reflection equal to the angle of incidence, and then communicating to those behind them the motion they have received from the reflection; whence it follows that the sound is diffused afresh in all directions, on returning from the obstacle towards the space it had previously traversed. In close places, such as apartments, the

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with oxygen gas, from nine to eleven tones higher than the air that surrounds us. A mixture of azote and oxygen, in the same proportions as in the atmospheric air, gave the same tone as the latter; but when the mixture of these gases was not uniform, the sounds were totally discordant. The experiments of Chladni and Jacquin were very different from those of Priestley and Perolle, on sound in different kinds of gases. The experiments of the last-mentioned philosophers related only to the intensity with which the vibrations of another elastic body (of a bell struck by a hammer) are conducted through these gases. Perolle contradicts Priestley's assertion, that the power of conducting is as the densities; but to this rule Priestley himself makes an exception in regard to oxygen gas, which appears to be a stronger conductor: azotic gas was examined by neither of these philosophers. In hydrogen gas they both found the conducting power very weak, which is no doubt owing to its little density. In oxygen gas they found the sound somewhat stronger than in common air; in the nitrous gas Perolle found it also somewhat stronger. In carbonic acid gas Priestley found the sound stronger; but Perolle, weaker, duller, and somewhat lower than in common air: which last circumstance we consider as agreeable to truth, because the vibrations of a sounding body must be more retarded the denser the surrounding fluid is, or according to its greater pressure on that body. One of these authors, Chladni, has made an observation which seems entirely his own. He observed, that when a plate of glass is agitated by means of a bow, if some dust is strewed over the glass, the former will appear to have arranged itself symmetrically, after the plate ceases to emit sound. Under the like circumstances the figures are always the same, their changes depending only upon the gravity or acuteness of the tone. This experiment proves that the motion of all the moleculæ of an elastic body is not necessary for the production of sound. For in the case before us, many parts of the glass remain perfectly immoveable, while the others oscillate about those points, which being fixed are called *nodes of vibration*. The same thing obtains in vibrating cords; as has been observed by Oersted, Libes, and our ingenious countryman Dr. T. Young. Tr.

sound is thus reverberated continually from one wall to another; and when the place is vaulted, or its sides have a sensible elasticity, we say that such place becomes sonorous, which signifies that the sound appears there to be prolonged, by succeeding to itself in such short intervals; that the ear does not distinguish between the several impressions which arrive at it one after another.

But if we are in the open air at a certain distance from the obstacle, a perceptible interval of time will elapse between the direct and the reflected sound, and we shall hear what is called an *echo*, which those who are not sufficiently attentive take for a simple repetition of the last words pronounced. It is hence easy to see why the poets who convert echo into an animated being place her habitation near mountains, rocks, and woods.

According as it is a single obstacle which reflects the sound, or as there are several obstacles disposed at suitable distances, the echo is simple or complex. Muschenbroek mentions an echo of this latter kind, which repeated the same sound as many as forty times. Two parallel walls which mutually reverberate the sound may produce a double or complex echo, with regard to an auditor placed in the intermediate space.

Art has disposed certain constructions of edifices, so as to produce, by means of reflected sound, a curious effect which is easily explained by geometry. The ellipse is known to have this property, that two radii vectores drawn from its foci, to any one of the points in its curvature, make equal angles with the tangent at that point. If, therefore, we suppose an arch or a wall of an elliptical figure, all the sonorous rays proceeding from one of the foci, will, after their reflection from the different points of the curve, pass through the other focus where they will concentrate the sound. In this manner, a person by placing his mouth at one of the foci, may pronounce in a low voice words which will be distinctly heard by an attentive observer at the other focus, and which will notwithstanding remain concealed from the witnesses stationed between the two interlocutors; so that none but the person placed to receive the echo can know the secret.

The Comparison of Sounds.

352. After having considered sound in its most general effects, such as the vibratory motion of bodies whence it originates, or of the air which propagates it, the velocity with which it is transmitted through that air, and its reproduction on meeting with bodies that reflect it; we have now to treat of the relations between sounds, compared according to the number of vibrations performed, in the same time, by different sonorous bodies. The observations which determine these relations spring from physics; and the art of the musician consists in employing them in a manner the best calculated to gratify the ear, either by the well ordered succession of simple sounds, on which melody depends, or by the happy combination of simultaneous sounds, in which harmony consists. The philosopher need only contemplate that which may be called *the music of the mind;* the professional man directs his attention to *the music of sentiment.*

353. Sounds admit of comparison always while they are appreciable. It is this quality of sound which enables the ear to distinguish its degrees, and gives to every man naturally the facility, when he hears any sound which is within the compass of his voice, to form one that imitates it perfectly, and that appears to be the same sound yielded by another organ.

This way of speaking of sounds, as being placed at different degrees one above another, and of supposing that the voice ascends and descends, is no other than a figurative language suggested by appearances, and to which the notation of music has been adapted.

Thus we give the name of *grave* sounds to those that are lower, and that of *acute* to those which are relatively higher.

Now the real and physical difference between a grave and an acute sound consists in this, that the body which yields the former makes a less number of vibrations in a given time than that which produces the second.

354. The experiments made on sonorous cords have furnished an easy method of finding the ratio between the numbers of vibrations from which two sounds result that differ from one another by a determinate number of degrees. In general the frequency of vibrations of a sonorous cord depends upon three things, namely, the length of that cord, its thickness, and its tension. The formula to which Taylor was led by his investigation is, that with equal densities the number of vibrations, in a given time, is proportional to the square root of the weight which stretches the cord, divided by the product of the length of the cord into its diameter; and this is confirmed by observation (*r*).

(*r*) Since the times in which cords vibrate (which are inversely as the number of vibrations), are in a subduplicate ratio of their weights and lengths directly, and an inverse subduplicate ratio of the tending forces, the particular note or tone of a given musical string stretched with a given weight may be known *a priori*; provided a single experiment be previously made, by observing the note which is sounded by a string in given circumstances. An experiment of this kind was made by the late Dr. Smith, and is fully described at pa. 202. of his valuable Treatise on Harmonics. Having fixed a harpsichord wire to a small cylinder of wood he suspended it so as to hang vertically at the side of the organ in Trinity College Chapel, Cambridge; and by turning round the cylinder, to which the string was affixed, was enabled to regulate its length, so that the tone should precisely coincide with any proposed note of the organ: the lower extremity of the string was defined by a loop to which a weight of 49000 grains was affixed, and it did not appear that any other terminations were

In the experiments relative to this object, an instrument called a *sonometer* is made use of; being a kind of oblong box, upon which are stretched by weights two brass wires, in order to compare the numbers of their vibrations (*s*).

necessary, either in the upper or the lower extremity, the vibration of the string not being extended lower than the beginning of this loop. When the tone of the string became exactly coincident with that of the lower D of the organ, its length was found to be 35·55 inches; and the string being cut at its two terminations, that is, at the beginning of the loop and at the place where it touched the wooden cylinder, the vibrating part of it weighed 31 grains. Here, denoting the length 35·55 by L, the tending *force* 49000 by T, the weight of the string 31 by *w*, and 193 inches the space described by a falling body in the first second by *g*, we have by a theorem investigated by Dr. Smith, N the number of vibrations in one second $= \sqrt{\frac{2gT}{Lw}} = 181$, in the present case; that is, the string in its vibratory motion passed the axis 131 times in a second. From this experiment it was inferred that the *middle* note denominated D in the organ vibrated 4 × 131 = 524 times in a second, and consequently impressed on the ear 262 impulses in the same time. This, however, was upon Trinity organ, which was then, by estimation, about a hemitone lower than the common pitch: accordingly, Mr. Atwood found 568 for the number of vibrations of the middle D of the usual scale, a result which agrees tolerably well with Dr. Smith's after making the proper allowance for the difference in pitch. The number of vibrations corresponding to any one tone being thus determined, it will be easy to ascertain the vibrations answering to any other note, by attending to the ratios stated by our author in the succeeding paragraphs: and it may be proper to add, that any crack, snap, or noise whatever when repeated with sufficient frequency, becomes *ipso facto* a musical sound, whose pitch or degree we can ascertain, by determining the frequency of its repetitions, or of the corresponding vibrations. Tr.

(*s*) Monochords differ principally from Sonometers in having *one* string only, as the name imports. The best contrived monochords with which we are acquainted are those of Earl Stanhope, and Mr. Atwood. In the Stanhope monochord the peculiarities are these;—1st. The wire is made of steel, which does not keep continually lengthening, like bras or iron. 2dly. The whole wire forms one straight horizontal line, so that the moveable bridge can be moved without altering the tension of the wire; which is not the case when the wire pulls downwards on the bridges. 3dly. The ends of the wire are not twisted round the two stout steel pins that keep it stretched; but each end of the wire is soft soldered in a long groove formed in a piece of steel which goes over its corresponding pin. 4thly. One of these two steel pins is strongly fastened by a brass slider, Commonly, only one of the three quantities of which we have spoken is made to vary: if, for example, we stretch the cords with different weights, we take those cords of the same thickness, and give to them the same length. In this case the relation between the numbers of vibrations during a certain time, assumed for unity, is indicated by the ratio of the square roots of the tending weights.

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which is moved by means of a screw with very fine threads, this screw having a large micrometer head minutely divided on its edge, and a corresponding *Nonius*; whence the tension of the wire may be very exactly adjusted. 5thly. A slider is fixed across the top of the moveable bridge, and is moved by means of another screw with very fine threads. 6thly. The slider is adjusted to the steel rod or scale, by means of mechanical contact against projecting pieces of steel firmly fixed on that steel scale, at the respective distances specified in the monochord table. 7thly. Each bridge carries a metallic finger which keeps the wire close to the top of such bridge while the remainder of the wire is made to vibrate. 8thly. The vibrations of the wire are produced by touching it with a piece of cork with the same elastic force, and always at the distance of one inch from the immoveable bridge.

The Stanhope monochord, though very ingeniously constructed, is in some respects inferior to the monochord contrived by Mr. Atwood. In this gentleman's apparatus the string hangs vertically, its tension being regulated by a weight suspended at its lower extremity, a little below the place where the string comes into contact with a fixed pulley; the length of the string is terminated at top by a horizontal edge: the other point of termination, which in the common monochords, as well as in many musical instruments, and in the Stanhope monochord, is a bridge over which the string is stretched, is in this construction effected by two steel edges vertically placed, that are capable of approaching, or of receding from, one another, like the cheeks of a vice; these, being fixed on a frame worked by micrometer screws, can be easily moved in the vertical direction, so as to alter the length of the string in any desired proportion: these edges are separated occasionally by a spring, in order to let the string pass freely through, when its length is altered, and are closed again so as to press the string slightly when that length is properly adjusted. By means of this construction the alteration of the tending force by the application of bridges, &c., is wholly avoided. The scale placed under the string of this monochord is divided into 100 equal parts, and each of these by a micrometer screw into 1000 equal parts; so that, by the aid of a microscope and a proper index, the length of a given part of the string may be adjusted on the monochord true to the $\frac{1}{100000}$dth part of its whole length. Tr.

If, in like manner, we represent by unity the lowest of the sounds to be compared, we shall have the following relations between that sound and the acute sound which is supposed to be heard at the same time with it.

The octave will be represented by 2; that is to say, the acuter sound will make two vibrations, while the grave sound makes only one; such is the interval between the sounds called *ut* in the ordinary gamut.

The quint or fifth, such as the interval from *ut* to *sol* in rising, will be expressed by $\frac{3}{2}$; thus the acuter sound of that consonance will make three vibrations to two of the grave sound.

The fourth, or the interval from *ut* to *fa*, will be represented by $\frac{4}{3}$.

The major third, or the interval from *ut* to *mi*, by $\frac{5}{4}$.

The minor third, or the interval from *mi* to *sol*, by $\frac{6}{5}$.

We shall here confine ourselves to consonances, or concords; we might represent the dissonances or discords in like manner, by varying in several other ways the two terms of the ratio.

355. Every sound, such as it commonly arrives at the ear, is to the judgement formed from that organ, a very simple effect, a kind of element whose purity nothing appears to alter; and yet every sound really comprises a multitude of other more acute sounds, some of which become perceptible in certain cases to a rather delicate ear, and the others have their existence indicated by different observations.

Let us first suppose that in a certain place there is only a single cord of a determinate length, as one of those that form the base of a harpsichord, or the thick string of a violoncello, and that after giving that cord a suitable tension it be made to resound. By applying an attentive ear at a small distance from the cord, we shall perceive, besides the principal sound, two other sounds, more feeble but very distinct; and if we always represent the principal sound by unity, the two concomitant sounds will be represented by 3 and 5 respectively; that is to say, if the first be *ut*, the second will be the octave of its rising fifth *sol*, and the third the double octave of its major third *mi*.

This experiment succeeds equally with a violin, when we pass the bow over the thick string, at a small distance from the bridge, in a direction nearly perpendicular to the string, so as to draw from the string a full and clear tone. The three other cords may be either suppressed or permitted to remain, at pleasure; for they contribute nothing to the effect.

The octave 2, and even the double octave 4 of the principal sound, may be heard; but in order to distinguish them a greater attention must be paid, because sounds placed at octaves one from another are much more likely to be confounded by the ear.

We have therefore the series 1, 2, 3, 4, 5, representing the different sounds perceptible to the ear, and constituting the harmony of a single sound.

But another experiment will induce us to think that these are only the first terms of a series which is indefinitely produced. For, if by the side of the former cord others are disposed whose numbers of vibrations corresponding to a single vibration of that, are 2, 3, 4, 5, 6, 7, 8, &c.; and if we cause the first cord alone to yield a sound, all the others will immediately vibrate and generate sounds, though much weaker than the fundamental sound. We may render their vibrations sensible to the eye, by placing upon each of them a little paper bridge, which will be seen to move, or even to be shaken off, at the moment when the principal cord is played upon.

If the diameters of the different cords are equal respectively, and at the same time there subsists an equality among the tensions, the lengths of the cords which the first will cause to resound, comprehending the unison, ought, from what has been said, to be as the numbers 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{6}$, &c. We shall in future suppose, for greater simplicity, that the cords only vary according to their length.

Now, since the first sounds of the series are immediately distinguished in the resonance of a cord which is caused to vibrate alone, there is no room to doubt that the following sounds are in like manner comprised in it; and if the organ does not distinguish them without some intermediation, it is because they are so weak as to escape its attention: and in addition to this we may remark, that, in certain cases, even with a single cord, we can perceive the impression of the sound represented by 7.

The name of *generator*, or *generating sound*, has been given to the principal sound; and the feebler sounds that accompany it are called its *harmonics*.

Some philosophers have thought that the principal cord subdivides itself into aliquot parts, similar to those which could represent the lengths of the other cords; so that the sound that would be rendered by each of them, was produced as a unison by the aliquot part corresponding to it in the principal cord. But neither observation nor calculus indicate this subdivision of the generating cord(*t*). All that can fairly be concluded from the ex-

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(*t*) There are some experiments performed first, we believe, by Dr. Wallis, which certainly favour this idea, though they do not completely verify it. If two strings the length of one of which is an aliquot part of the other, be of equal thickness, and equally stretched, any vibrations given to the shorter string will communicate themselves to the corresponding parts of the longer string placed near it. If the vibrating shorter string be an acuter octave, the other will vibrate by its half lengths only: if the string which communicates the motion be an acuter double octave, or a fourth of the length of the other, the longer string will vibrate only by the fourths of its lengths from one end to the other. Thus, if one string were four feet long, and the other one foot: on striking the latter with a quill the vibrations will be communicated to the former so that it will only vibrate in foot lengths throughout: this may be made evident by hanging little paper bridges at every foot length of the longer string; for, on the vibrations being communicated to it, the papers hanging at the *middle* of each foot in length will be thrown off, while those that hang at the *end* of each foot will remain unmoved upon the string; whence it is inferred that the vibrations are made about those points as so many fixed points, the intermediate spaces having each its separate vibration. See also par. 358. Tr.

periments cited is, that the vibrations of a sounding cord have the property of exciting in the air, not only vibrations of the same order, but other vibrations of different higher orders, analogous to those which the harmonics would have produced if each of them were yielded by a distinct cord.

It may perhaps be thought also that when a single cord is employed, the resonance of the harmonics proceeds from the surrounding bodies, whose fibres are found in unison with those harmonics; for example, from the fibres even of the wood on which the cord is stretched, and with which that cord is considered as communicating; in such manner that the cord commences an action upon those fibres, while they in their turn would produce separate vibrations in the air analagous to the resonance of harmonics. But we have made the experiment in the open air, and so contrived the apparatus that the points to which the cord was fixed had no perceptible elasticity, and notwithstanding these precautions, we have heard the sound of the first harmonics: whence it must be inferred that the cord has, of itself, the property of exciting in the air such vibrations as produce the concomitant sounds; and that those are the vibrations which afterwards cause the surrounding bodies to tremble and resound.

356. Reasoning from the facts we have just stated, it will be easy to comprehend why, when a person sings in a place where there are bodies susceptible of yielding appreciable sounds, as vessels of glass or metal, each of those bodies will resound, when the voice generates a sound in unison with its own peculiar note, or even when it renders a sound which is to that given out by the same body on percussion, as the generating sound is to its twelfth (or the octave of its fifth), or to the double octave of its third. These different effects are very sensible, when we produce a sound with the voice, by presenting the mouth to the top of a common drinking glass. The most manifest resonance is that of the unison; and we have heard of

singers endowed with a voice so exact and powerful, that by taking thus the unison of the glass, they were able to break it by the voice alone. The change of figure which was, in this case, undergone by the different annuli that compose the glass, is so considerable, that the parts have not the flexibility necessary to yield to it with sufficient promptness, and therefore separate from one another in different places, as in the case where the glass was subjected to a strong percussion.

357. What we have been mentioning leads us next to speak of another experiment, known under the name of *Tartini's Experiment:* it consists in causing to be heard at once two strong clear and continued sounds; from their concourse there results a third sound which is weaker, and is such, according to this celebrated musician, that if the relation between the two former sounds be represented by the most simple numbers, the produced sound will be represented by 2 (*u*). If the two primitive sounds are, for example, expressed by the numbers 8 and 9, in which case their simultaneous occurrence will give a dissonance similar to that which results from the sounds *ut*, *re*, the produced sound being 2, will correspond to the double octave below the *ut* of the dissonance.

In general, we need only to remove by an octave one of the simultaneous sounds, or both of them, that they may be comprised in the series of harmonics, of which the third sound would be the generator: hence, this experiment may be connected with that of a triple resonance of a vibrating cord, of which it presents, in some sort, the reverse.

358. We shall cite a third and very curious experiment which was first pointed out by Wallis, but which was neglected till it occurred in the observations of Sau-

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(*u*) Rameau is the real author of this experiment: he presented to the Society of Montpellier in 1753, some time before Tartini's work appeared, a memorial printed the same year, in which the experiment is fully described. Tr.

veur, who has since passed for its inventor. The experiment is this:

If we stretch a musical cord above a board, and divide it into two unequal portions yet respectively commensurable, by means of a slight obstacle which only presses moderately; those two parts being struck successively will yield the same sound, which will be different from that of the whole cord: and such indeed will that sound be, that if we represent by the most simple numbers the ratio between the lengths of the two parts of the cord, the sound which is heard, the slight obstacle being interposed, will be that of a cord which is represented by unity. Thus, if the cord were divided into two parts, which are respectively as the numbers 3 and 2, in which case the corresponding sounds would be in the relation of *ut* and *sol* rising, if the lengths of the two parts determined their resonance; then the sound yielded by each part of the cord will be that of the cord 1, that is to say the *sol* which is the acute octave to the sound given out by the smaller portion in the ordinary case.

It would seem, then, that each part subdivides itself into as many equal portions, as the number that measures it contains units. Hence, between two neighbouring subdivisions there is a point of rest or a node, and at the middle of each subdivision the undulation forms a bellied part, as in a cord which vibrates from end to end. In the preceding example, the larger part subdivides itself into three, and the smaller into two; so that the sound *ut* is rendered at once by all the subdivisions, which are thus found in unison one with another. It is obvious that the smaller part ought not to subdivide itself when the sound to which it is analagous has the unit for its expression; for then the same sound is yielded by the smaller part, as by each of the subdivisions of the greater.

Such, therefore, is the mechanism on which the series of unisons given by this experiment depends, that the slight obstacle which divides the cord merely prevents the total vibrations, but permits a communication to subsist, or a mutual dependence between the two parts, whence their vibrations tend to accord perfectly, or, in other words, to become isochronous. Of consequence, they are forced to subdivide themselves, but they do this as little as possible: so that the number of subdivisions is always the smallest among all those which would furnish isochronism.

Thus, in the preceding example, if the cord 2 made total vibrations, the two-thirds of the cord 3 might be able to put itself in unison with it; but there would remain one third which would perform its vibrations separately: now, it is this third which being alone proper to determine the isochronism, gives law to all the rest.

Sauveur rendered sensible to the eye the distinction between the nodes and the moveable parts, by placing at the point of each node a chevron of white paper, and another of coloured paper about the middle of each vibrating part. At the moment when the cord commenced vibration, all the coloured pieces were seen to fall off, while all the white ones remained in their places. This experiment will succeed very well, if we use a violin string, by dividing it with a bridge of pasteboard, after having stretched it upon a board; and making it vibrate by lightly drawing the bow across near to the wooden bridge on which either extremity of the string rests.

359. The first of the experiments we have cited, or that which consists in the triple resonance of a vibrating cord, will furnish us with some reflections on the formation of our diatonic scale, composed of the sounds *ut*, *re*, *mi*, *fa*, &c., well known to every one (*w*).

(*w*) When Guido Aretino substituted his hexachord instead of the ancient tetrachord, he adopted the syllables *ut*, *re*, *mi*, *fa*, *sol*, *la*, to the various sounds which compose it, from the following Sapphic verses in a hymn to St. John:

If the primitive sound *ut* be always represented by unity, the series of the eight sounds will be expressed by that of the numbers below:

$1, \ \frac{9}{8}, \ \frac{5}{4}, \ \frac{4}{3}, \ \frac{3}{2}, \ \frac{15}{9}, \ \frac{15}{8}, \ 2;$
ut, re, mi, fa, sol, la, si, ut:

that is to say, if vibrations were communicated to cords whose lengths were proper to give the number of vibrations that correspond to the terms of the preceding series, we should have a succession of sounds which would very accurately represent our gamut,

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UT queant laxis *REsonare fibris*
MIra gestorum *FAmuli tuorum*
SOLve polluti *LAbii reatum.*

SANCTE JOANNES.

The introduction of the seventh syllable *si* is generally attributed to Le Maire, a French musician of the 17th century; though some ascribe it to Vander Pullen, and others to Jean de Muris.

The names of the seven notes used by the French are retained in this translation, as we believe, that, if properly associated with the sounds which they denominate, they will tend to impress these sounds more distinctly on the memory of the student than the letters C, D, E, F, G, A, B; from which except in solfa'ing, the notes in the natural diatonic series are generally named in Britain. Amongst us, in the progress of intonation, the syllables *ut*, *re*, and *si*, have been omitted; by which means the teachers of church-music especially have rendered it still more difficult to express by the four remaining denominations the various changes of the semitones in the octave. As these artificially change their places, the syllables above mentioned are variously arranged, according as the intervals in which are the notes they are intended to signify may be placed.

We may take occasion to observe concerning the musical scale, that the intervals between *ut* and *re*, *re* and *mi*, *fa* and *sol*, *sol* and *la*, *la* and *si*, are equal in practice, and nearly equal in theory; and that the intervals between *mi* and *fa*, and *si* and *ut*, are likewise nearly equal respectively: yet these intervals are each only about half the former, and are therefore usually distinguished by the name of *semitones*, while the former are denominated *tones*. The scale of the octave may, hence, be divided into two equal parts,

ut, re, mi, fa;
sol, la, si, UT:

in which the first division, as well as its respective subdivisions, is perfectly similar to the last. TR.

such as each sound appears to the ear when executed by singing. This gamut is very ancient: for, by enquiring into the history of the Grecian ages, when a taste for the arts was so ardently cultivated, it will be found, that the two tetrachords which constituted the musical scale of those times, had their sounds precisely in the same relation as those of our scale.

Now, it is remarkable that the gradation of sounds in these two scales, is found subjected to the principle of the greatest simplicity in the determining relations; and this principle appears to have been the secret guide whose indications have been followed by the ear. To conceive this, it must be observed that by taking the sounds that give two, three, four, and five vibrations, in the time of one only of the fundamental sound, we shall have successively the octave of its fifth, afterwards its double octave, and lastly the double octave of its third: that is, we shall have the harmony of the sounds which are the only ones heard sensibly, when we make an insulated cord vibrate. But the octave, the fifth, and the third, are the most perfect consonances, and all our diatonic scale depends upon them. For, in the first place, we have in this gamut the concord *ut*; *mi*, *sol*, which is given immediately by the triple resonance of the sonorous body, except that the *sol* and the *mi* are found transferred, the one to the octave, and the other to the double octave below the corresponding harmonic; which is always allowable, because of the great resemblance between a sound and its octave. Let us now transfer the *fa* and the *la* of the gamut to the octave below; if we connect the *ut* fundamental with these two sounds, we shall have a new concord *fa*, *la*, *ut*, entirely similar to the concord *ut*, *mi*, *sol*. Lastly, if we transfer the *re* to the octave above, we shall have, by combining with it the sounds *sol* and *si*, a third concord *sol*, *si*, *re*, which in like manner is exactly analagous to the concord *ut*, *mi*, *sol*. Thus, therefore, may all the sounds of the gamut be distributed between three concords composed of a third, and a fifth, and so connected one with another, that the fundamental sound of each is either the graver or the acuter fifth, to that of the other; so that by beginning at the *fa* taken below the fundamental *ut* of the gamut, we have this series *fa*, *la*, *ut*, *mi*, *sol*, *si*, *re*, which forms a concatenation of thirds and fifths. Hence, our gamut is limited to the combinations that furnish the sounds represented by the first five natural numbers; all the other numbers are excluded; in reference to which Leibnitz remarked pleasantly enough, that *the ear reckoned no farther than five.*

360. On the other hand, some philosophers have thought there was another gamut preferable to the preceding, and whose adoption would elevate music to its true point of perfection. The observation on which they found their opinion is this:

If in the series of harmonics yielded by the different cords that resound by the side of a first cord which is made to vibrate, those are taken that correspond to the fractions $\frac{1}{8}$, $\frac{1}{9}$, $\frac{1}{10}$, $\frac{1}{11}$, &c., to the $\frac{1}{16}$ inclusively; we shall have a succession of sounds similar to the ordinary gamut, except that the *fa* and the *la* will be a little higher than in that gamut, and that the harmonic $\frac{1}{13}$ will give a supernumerary sound between the *sol* and the *la*.

The philosophers adverted to, have imagined that this latter ought to be the true gamut, since it was furnished immediately by nature; and that if the ear appeared offended by the intonation of the sounds *fa* and *la*, when this gamut was produced by an instrument adapted to that effect, such as the bugle-horn, it was the result of a prejudice of that organ acquired by habit, but which would soon be conquered on becoming familiar with the scale proposed, and permitting free action to nature, who would soon recover her rights.

Yet the reason that is deduced from the simplicity of the ratios will appear to preponderate, if it be considered that this simplicity is connected with the facility of perceiving the intervals between the sounds, which in its turn affects the gratification of the ear. Hence it happens that the octave is the concord which pleases the most universally, and that after this the perfect concord, composed of the fifth and the third, finds so easy an access to all ears which are not deaf with regard to harmony. But it is of this concord and that of the octave, as we have seen, that our gamut is made up. We confine ourselves within these limits, by a kind of instinct, and previously to all study of the harmonical properties of sonorous bodies. It is not that the ear compares numbers; that comparison is solely within the jurisdiction of the mind; but the simplicity of those numbers appertains to a physical effect, namely the frequency of coincidences of the terms limiting the vibrations of the sounds compared, an effect that seems to find a disposition even in the organ of hearing, in virtue of which it better accommodates itself to that which is more simple, since it can enjoy it with less exertion.

361. Art, by taking intermediate sounds between those suggested by nature, has imparted a great variety to the effects of harmony and melody, and has been enabled, by the ingenious combination and arrangement of dissonances and consonances, to convert into a gratification to the ear, that which appeared only calculated to produce unpleasant sensations.

362. Rameau has attempted to deduce the law of harmony from the triple resonance of sounding bodies: and Tartini believed he had discovered their origin in the experiment we have cited under his name (357).

But these systems furnish merely probabilities more or less plausible, and there are phenomena of harmony avowed by the ear, which cannot be reduced to either of them.

363. What has been already stated may assist us in presenting some notions relative to that which is denominated *temperament*.

It results from the principle on which our gamut has been formed, that the acuter sound of each of the three perfect concords, whereof it is composed, makes a perfect fifth with the fundamental sound of that concord. But if two sounds be compared taken in different concords, such as the *re* and the *la* forming likewise a fifth, there will then be found a small alteration in the accuracy of that interval. For the ratio of these two sounds is that of $\frac{9}{8}$ to $\frac{15}{9}$, or of 27 to 40; a little greater than that of 2 to 3 which corresponds to a perfect fifth. In order that the *la* might be with the *re* in the relation of that fifth, it would be necessary that its expression should become $\frac{27}{16}$. Let us for a moment suppose this to be its expression, and let us take above this same *la* a new sound *mi*, making also a perfect quint with it; we shall have the expression for that *mi*, by multiplying $\frac{27}{16}$ by $\frac{3}{2}$, the ratio of the quint; whence we have $\frac{81}{32}$. Now, if there had been no alteration in the intervals, this *mi* would be a perfect acuter octave to that of the gamut. Yet this is not the case: for if we raise this latter *mi* an octave, its expression, which was $\frac{5}{4}$, will become $\frac{10}{4}$, or $\frac{80}{32}$, less than $\frac{81}{32}$ in the ratio of 80 to 81. Hence it follows that the *mi* expressed by $\frac{81}{32}$ cannot but be more than the third of the *ut* whose expression is 2; the ratio between that *ut* and the *mi* in question, reduced to its greatest simplicity, is that of 64 to 81, a little greater than that of 1 to $\frac{5}{4}$, or of 64 to 80, which belongs to the *ut* and the *mi* of the gamut.

Without entering more into detail in this place, it may suffice for us to remark, generally, that of these three intervals, the octave, the fifth, and the third, we cannot preserve any one in all its purity, without altering the two others; and hence has arisen a difficulty which has been long acknowledged, relatively to the manner of tuning stringed instruments (such as harpsichords) where each touch corresponds to a sound whose degree is determined by the operation itself. In consequence of this, various methods have been contrived to furnish a system of *temperament*, that is to say, to combine the alterations in such manner that the harmony should not suffer perceptibly: and all these methods concur in this point, that it is indispensable to retain the accuracy of the octaves by sacrificing some little of that of the fifths and the thirds; since it is nearly with regard to the octave as the unison, which, on account of its great simplicity, is so agreeable to the ear, that it cannot tolerate the least defect in its precision: the ear, however, rather relaxes its severity with respect to less simple intervals; in this case gratuitously supplying their deficiencies, by supposing those differences not to exist which it cannot appreciate.

Rameau, after having hesitated long as to the choice of the best temperament, finished by adopting that in which all the fifths are found equally altered, seeing that no reason could be adduced why one should be modified rather than the other. It has been remarked, however, that in this system the thirds would become harsh and offensive; the method has therefore been generally adopted, to which Rameau himself, at first, gave the preference, though he afterwards abandoned it. In the instruments tuned by that method, the fifths given by the natural tones of the gamut retain their harmony almost entirely; the most perceptible differences resting upon the intermediate semitones: the musicians have taken in the series of fifths, certain notes by which they verify their operation from time to time, judging by the accuracy of some other concord, such as that of the third, which each of those notes ought to make with one of the notes previously tuned. Hence there results a great diversity in the alterations undergone by the intervals of the fifth and the third which constitute the series of the different sounds; and this diversity has even been regarded as an advantage: for, according as one or other sound has been chosen in preference for a fundamental, that is to say, for that to which all the others are referred, in such manner that the modulation rests, so to speak, upon that note as on a base, the fifths and the thirds which pervade the song have something of a dull cast, calculated to excite pensiveness and melancholy, or I know not what of refinement and sprightliness which inspires joy. Thus the modulation borrows from the peculiar manner in which the intervals it employs have been altered, a characteristic tint which it supports of itself; and that which many have been tempted to regard as a defect, becomes, in the hands of the musician, a means of adding to the expression of the sentiment he wishes to depict (*x*).

364. It remains for us to establish the theory of the different phenomena presented by experience, relatively to the propagation of sound, and to explain how it happens that sound retains a uniform velocity, in its course from the sonorous body to the organ of

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(*x*) The subject of Musical temperament is too comprehensive and important to be sufficiently discussed in the space assigned to it by M. Haüy: yet it is a topic which is worthy the closest attention of all who study the philosophy of musical sounds. We therefore beg to refer the reader to Dr. Smith's valuable work on Harmonics, and to the excellent article TEMPERAMENT, in the Sup. Ency. Britan., for more useful information on this point than in any other English works we are acquainted with. An abridgment of some of Smith's propositions is given in the late Bishop of Clonfert's Syllabus of his Lectures; and an account of Earl Stanhope's Temperament, in No. 7, of the Retrospect of Philosophical, &c. Discoveries. TR.

hearing, although it loses continually more and more of its force; how it happens that sounds acute and grave, strong and feeble, have the same velocity in their progress; and lastly, how different simultaneous sounds cross one another in the air without forming a confused noise, but convey their harmony to the ear in all its clearness and purity.

This theory is deduced from the manner in which sound is formed in wind instruments; and we have extracted it from an excellent Memoir, where Daniel Bernoulli has developed the principles and subjected them to calculation. We shall endeavour to exhibit as perspicuously as possible the ideas of this celebrated mathematician.

Let us, in the first place, imagine a cylindric tube to be stopped at one end, and that it is caused to sound by blowing at the open orifice. The air included in this tube will be made to vibrate, in such manner that each of the infinitely thin laminæ or strata which constitute the column of that fluid will alternately approach towards the bottom and recede from it, by going and returning from one side to the other of the position which it had in the state of rest, by little oscillations similar to those of a simple pendulum. These oscillations go on increasing one stratum after another, from the bottom where they are next to nothing, to the orifice where they are the greatest: those of each stratum will be isochronous and those of the different strata will be synchronous, that is to say, they will all commence and terminate in the same time; otherwise they could not form a sound.

While the different strata will have a progressive motion towards the bottom, that which was at the orifice will enter the tube, where it will condense the neighbouring stratum; and so throughout, in such manner that the condensation will always go on increasing to the bottom, where it will be at the greatest, because it will result from the concourse of all the actions of the posterior strata. On the contrary, in the return towards the orifice, there will issue from the tube a small portion of the air which was contained in it during the state of rest, and the several strata will experience little dilatations which will go on diminishing from the bottom; whence it appears that the air situated just at the orifice, will be neither condensed nor dilated, but will retain the same density as the surrounding air.

365. Such are the circumstances that obtain in tubes closed at one end. Let us next apply this hypothesis to the vibrations of the air included in a tube open at both ends. Now, the only idea that accords with the laws of mechanics and with observation, consists in the supposition that the tube is divided into two halves by means of a thin partition, as if it were composed of two tubes, each open at one end and joined at their common bottom. It will result that the stratum of air situate at the place of the partition, or to speak more correctly, which performs the office of a partition, will be immoveable, and that all the other strata will perform oscillations, which will go on increasing on both sides, conformably to the law above explained.

366. It remains to consider the case of a tube closed at both ends, which, although it never occurs in practice, is necessary to complete the theory. If it be supposed that the interior air is put into vibration by any cause whatever, we may conceive of each half as of a tube closed solely at one end, and in which the oscillations will be the same as in this last kind of tube, but in such manner that they will be made all in one direction from one bottom to the other; and thus, while the strata comprised in one moiety will be successively condensed by approaching the bottom which terminates it, the strata of the other half will successively dilate while proceeding in the same direction as the former,

and the density of the middle stratum will be constant.

It is obvious that the two latter cases are merely consequences of the hypothesis assumed with respect to the first; and if that hypothesis adapts itself with facility to the various facts furnished by experience, we cannot refuse to consider it as extremely probable.

367. Now, it is well known that a tube which is open at both ends, yields the same degree of sound as a tube closed at one extremity, and only half the length of the former. This is a necessary consequence of the principles of the theory, since in the tube open at both ends the air in the middle is in a state of repose; so that the two halves are in unison, and the oscillations of the air in each of them are perfectly similar both to one another, and to those that obtain in the tube closed at one extremity.

368. In certain wind instruments, such as the bugle-horn, and the trumpet, where the effect is produced independent of the play of the fingers, the difference in the tones depends upon the manner of enlarging or contracting the opening of the lips, according as the musician would produce a graver or an acuter sound. He modifies the degree of this opening by the sentiment he has of the sound he wishes to create; but he cannot give birth to every tone at his will. The instrument only conforms to his wishes as far as is agreeable to its nature. Consequently, if the principal sound be represented by 2, the musician can only produce upon such instruments those sounds that correspond to the numbers 4, 6, 8, 10, &c.

Now, to explain this determinate progress of sounds successively more acute, we need only consider the instrument as a tube open at both ends. In the case of the fundamental sound represented by 2, such is the degree of pressure given by the musician to his lips, that the resulting order of vibrations develope themselves in an extent equal to the half of the tube: at the middle point there will be formed a partition of stationary air, or a node, beyond which similar vibrations will re-commence, but in a contrary direction.

But, suppose the musician to increase the pressure of his lips, to the degree corresponding to the octave above the fundamental sound. The new order of vibrations relative to this sound will occupy only half the extent of the preceding ones: there will, therefore, be a first point of repose at the quarter of the tube, and a second at the third quarter, in such manner that the first and last part will each represent a tube stopped at one end, and the intermediate part a tube closed at both ends, but of a double length; and thus the whole will be equivalent to four tubes each stopped at one extremity, which will be all in unison, and each will yield the sound denoted by the number 4.

In the more elevated sounds, the tube becomes divided successively into 6, 8, 10, &c., equal parts, which may be compared to so many tubes each closed at one end. The extreme tubes may be considered as single, and the intermediate ones as united two by two to compose the tubes closed at both ends, and each double either of the extreme tubes. There will therefore be a node at the place of each partition, and a swoln part at the middle of the distance between two neighbouring partitions. The vibrations which have their origin at the same node are performed on both sides by contrary motions, but they take place in the same direction on both sides of the same inflated part.

The musician will make inefficient attempts to draw from the instrument any sound whose degree cannot be found upon the scale defining that law; or if any such sound should be obtained it can only be by a particular artifice, which will produce the same effect as if the form of the instrument were changed, as when he who blows the bugle-horn puts his hand into the pavilion or mouth of the horn.

369. A new experiment, which confirms the theory, consists in boring a lateral hole in any part of a sonorous tube where a node is situated; though this hole be left uncovered, the sound will remain the same: but if the aperture be made elsewhere, the degree of the sound will be elevated, because the air being not in a state of rest in that place, will diffuse itself outward by reason of the vibrations, which, experiencing less obstruction than when the tube had no such aperture, would accelerate their motion. This may serve to render manifest the general principle to which is referred the construction of flutes and other similar instruments, from which different tones are drawn, according as certain of the lateral holes are closed or opened(y).

370. The oscillations that excite sound in conical

(y) Malcolm observed in his Treatise of Music, that any wind-instrument being over-blown, the sound will rise to an octave and no other concord; and his remark has been many times repeated: but the theory of wind-instruments given above shews that Malcolm's opinion was incorrect as to this point. And indeed almost every performer on the German flute can contradict the assertion by referring to his own experience: since he knows that by varying the conformation of his lips, and the velocity of the breath he propels into the instrument, he can produce (without changing the position of the fingers) not merely the octave, double octave, &c., but the fifth above the former, the major third above the second, and so on, according to the series of the natural harmonics.

We may avail ourselves of this note to observe, that since M. Bernoulli has shewn the complete analogy between the accelerations of the different points of an elastic chord and of the corresponding plates of a column of air, it legitimately follows that all the consequences which we can fairly deduce, respecting the vibrations of an elastic cord, may be affirmed respecting the undulations of a column of air in a pipe. Hence we may readily derive a compendious rule for determining the absolute number of aerial pulses made by an open pipe of any given length; for tubes differ, in some respects, from those that take place in cylindrical tubes. The most remarkable difference consists in this, that the tremours of the air on which they depend constantly diminish with the distance from the vertex of the cone; so that the excursions of the different strata are themselves always smaller and

the weight of the atmosphere produces in regard to a sounding cylinder of of air, the same effect as that produced by the weight that stretches a string. The theorem we have given in note (*r*), if we substitute for g its value 193 inches, will become $N = \sqrt{\frac{386T}{Lw}}$. Let H be the height of a homogeneous atmosphere, then, L being the length of the pipe, and w the weight of the air included, we have the weight of this atmosphere $= \frac{Hw}{L}$: this being equivalent to T in the preceding formula, must be substituted for it, and there will result $N = \frac{\sqrt{386H}}{L}$. Now, the numerator of this fraction computed in inches is about 11331 : if, therefore, we measure the length of the pipe L in inches, the pulses in a second will be $= \frac{11331}{L}$. Computations founded upon this theorem agree nearly with Dr. Smith's experiments, as well as with the observation that a French horn, or an open flute pipe, of about 16 feet long, or an organ pipe of 8 feet long, yields the sound *C-fa-ut.*

If the height of the homogeneous atmosphere varied as the air near the earth expanded or contracted, the above theorem would give true results in all circumstances: but this is not the case; and it may happen that the pressure of the atmosphere may be augmented, while the density of the air included in a pipe may be diminished, a change which will obviously produce an elevation of tone. Thus, it is found that during serene or warm weather the pitch of wind instruments is raised, while during stormy, moist, or cold weather it is lowered : such indeed is the difference thus produced, that Dr. Smith found his organ a full quarter of a tone higher in summer than in winter. Wind instruments also emit an acuter sound in proportion as themselves, or the included air, become heated: the case being exactly the same as if an elastic cord should become less, and still be stretched with the same weight. The effect of this is often felt in concerts of wind instruments with stringed instruments : the heat which sharpens the tone of the former, flattens that of the latter; and consequently such instruments as the harpsichord, soon get out of tune with the horns and the flutes. TR.

smaller, according to the inverse ratio of the distance from the summit.

But this difference alters neither the distance between the most inflated parts, which is every where the same, nor the duration of the vibrations, which also retain their isochronism in all cases.

371. We may now apply this theory to the propagation of sound. In every sonorous ray, which is, as we have said (348), an indefinitely narrow cone of air, what passes is similar to that which happens in a conical tube wherein the air performs its vibrations; in other words, there will be a succession of nodes and of points which correspond to the greatest excursions.

As there is an inflated part (or one of greatest excursion) at the origin of the cone, and all such parts are equally distant, we may separate mentally the whole cone into a series of truncated cones, equal in length, each of them having two such inflated parts at the place of its bases, and a node situated towards the middle. Bernoulli gives to these truncated cones the name of *concamerations*.

At the moment when the sonorous body begins to vibrate, the whole air will not undulate at once which is in any of the cones that have their summits at the different points of that body; the tremours will only be communicated to the first concameration: when that has made one oscillation, it will give motion to the air in the second concameration; at the end of a new vibration, the oscillations will commence in the third concameration, and so on throughout. Hence we may see why the propagation of sound is not instantaneous, but requires a certain time which always becomes more considerable in proportion as the distance itself augments.

The oscillations that have place in the different successive concamerations are perfectly isochronous: and farther, all the concamerations are equal in length.

Therefore the sound ought to run over the series of all these concamerations with a uniform velocity; which was one of the effects we proposed to explain.

Now in proportion as the concamerations remove from the summit, the tremours of the air which produce the little partial oscillations of which each total oscillation is composed, continue to diminish, while the isochronism always subsists notwithstanding: whence it follows that at a greater distance the organ will be more feebly affected, and the sound less heard; so that at a certain distance it will be completely extinguished.

Whether the sound be strong or weak, the duration of the vibrations and the length of the concamerations will remain the same, because it is the degree of the sound alone which determines both; as it is easy to infer from the circumstance that the tone yielded by a tube is the same, whatever is the force of the breath which causes the air to vibrate, provided the opening of the lips be likewise the same.

372. If we suppose two sounds that are octaves one to another, to be heard either successively or together, the concamerations depending upon the acute sound will be as short again as those which correspond to the grave sound; they will, therefore, occur as often again in a given space. But the oscillations of the air in each of these are performed in half the time; whence it results that they employ the same space of time to propagate themselves to the same distance: and thus the degree of sound (as to grave and acute) has no influence upon the velocity, which in like manner agrees with observation.

373. The preceding may suffice for what regards solitary sounds. But when several bodies vibrate at the same time; when in a concert, for example, many instruments and many voices yield at once sounds of various degrees, how does it happen that the different

vibrations that result, meet in their passage through the air, without being destroyed or turned out of their course by their mutual encounter, and that each of them afterwards continues on its way towards the ear as though it had found the passage completely unoccupied?

Most modern philosophers have attempted to resolve this difficulty by adopting the idea of Mairan, who supposed the air constituted of particles of an infinite variety of different magnitudes, any one of which was only capable of receiving and transmitting the vibrations that depend upon one particular tone. Hence when several sounds concurred in the same harmony, or in any other manner, each of them merely addressed itself, as it were, to the particles which were in unison with it, and exercised upon them an action independent of that which would be experienced by the moleculæ of a different diameter. But without recurring to this gratuitous supposition, which, to unravel a complicated effect, employs a complication of another kind, and gets quit of the difficulty only by transferring it to another place; we may deduce even from the theory which we have laid down a satisfactory method of elucidating the distinction of simultaneous sounds.

374. This elucidation rests upon the general observation that all such minute motions as have points of concourse, become, in some measure, superposed some upon others without being confounded. To render this idea more manifest, let us consider two sonorous rays, which meet one another under two different directions: the motion will be compounded in the small space where they intersect, in such manner that the little oscillations which have place in one ray, by giving a slight impulsion to those of the other ray, produce, in the moleculæ situated at the point of concourse, other oscillations in the diagonal. Let us imagine an observer whose eye will be capable of tracing the progress of the oscillations; and suppose that this eye itself performs little oscillatory

movements, similar to those that the moleculæ of one of the two rays would have made on the analogous side of the parallelogram whose diagonal is described in virtue of the real motion. This eye will perceive the moleculæ which follow this latter motion to oscillate, as though they were moved in the direction of the other side of the parallelogram; that is to say, the eye itself having one of the motions which are compounded into the diagonal, and this motion being considered as destroyed with regard to it, will only receive the impression of the other motion. Now it is easy to infer from hence that the moleculæ of air situated beyond the concourse of the two rays, to which the motion that exists with regard to the observer solely would be communicated, would not yet cease to receive it; since they are in the direction where the vibrations that are performed in the diagonal ought, by decomposing themselves, to produce that same motion. This reasoning being applicable to the other sonorous ray also, it will be evident that the vibrations, after being confounded in a space almost infinitely small, ought to get clear of one another again, and return to their former paths, as though they had never experienced any such concussion*.

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* To throw a new light upon this explication, let us conceive that *a c*, *bc*, (fig. 32.), represent the directions of two sonorous rays, which intersect each other at the point *c*, and that *h c*, *m c*, measure the extent of the little oscillations that obtain near the point of concourse. The motions due to these oscillations are so compounded in that point, that the single motion which results transfers itself to the particles situated immediately below *c*, and there gives birth to other oscillations in the direction of the diagonal *c r* of a minute parallelogram *c n r s*, determined by the lines *c n*, *c s*, situated upon the prolongations of the lines *h c*, *m c*, and equal to those measures. Now the oscillations in the diagonal resolve themselves at the point *r* into two motions, whose effect is such, that the moleculæ situated upon the lines *r t*, *r u*, the one parallel to *b c*, the other to *a c*, are solicited to perform oscillations equal to the former, and coinciding with those lines *r t*, *r u*. But the space in which all these motions are performed being almost infinitely small, the lines *r t*, and *r u*, are, as to sense, in the same directions as the lines *b c* and *a c*; so that the oscillations obtaining in

375. It is by a mechanism of a similar kind that the little successive undulations produced in water into which several stones have been cast, pass one over another without becoming confounded, and produce circumferences that mutually intersect. But the same thing does not obtain in great motions; for there the moleculæ that are situated at the point of concourse receiving strong impulsions on different sides, are carried away in their turns by a motion which causes them to deviate totally from their original directions.

376. Such is the point to which the theory has been carried: but what remains inexplicable is that species of suppleness of the air, to receive, in some sort, the impression of the different characters of which the same tone is susceptible, by reason of the diversity of the bodies which yield it, and to modify itself in so many ways while conveying to the ear the soft and feminine tones of one instrument, the more vigorous and masculine sounds of another, and the infinitely varied accents of the human voice. We know not which ought to be most admired, the nature of the fluid which delivers those different messages with a fidelity so exact, even to the minutest details; or that of the organ which discriminates all with so great a delicacy of touch, and comprises in its fibres the unisons to so many particular modifications of sound (z).

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the sense of the latter lines, are considered as propagated in their prolongations beyond the point of concourse *c*. Hence, the resultants of all the little decomposed motions may be contemplated as lines infinitely short, or as simple points, which only transmit those motions, without altering their directions.

(z) Daniel Bernoulli's theory, a popular represensation of which is given in the preceding pages, was first published in the Memoirs of the Paris Academy for 1762 His hypothesis corresponds to a very considerable degree with the chief phenomena observable in wind instruments of the flute and trumpet kind. Many philosophers are not entirely satisfied as to the accuracy of his assumptions respecting the state of the air, and the precise form of the undulations he assigns to it: although, however, there is a probability of his being mistaking in these points, and although his reasonings on the distinct propagation of simultaneous sounds are by no means so convincing as might be wished; yet we cannot refuse our assent to his chief propositions, and we conceive his whole theory to approximate nearer to the truth than any other which has hitherto been advanced. Those who wish to know more of this theory, and have not an opportunity of consulting the memoir mentioned above, are referred to the article TRUMPET, *Musical*, in the Sup. Ency. Britan. TR.

V. ELECTRICITY.

377. Electricity is one of the branches of our knowledge which modern philosophers have cultivated with much assiduity and success. It was no farther known at the commencement of the last century, than by the attractions and repulsions which glass, yellow amber *, resins, and other similar substances exercised upon minute bodies presented to their action, and by a faint light which was disengaged from those substances by friction. About 30 years afterwards the researches of Dufay and of Grey introduced one of those fruitful epochs at which a science begins to develope itself by a rapid progress, and the discoveries press closely one upon another. A more attentive examination of phenomena led to the establishment of the important distinction between the bodies which transmit the electric fluid, and those which refuse to propagate it: the construction of more ingeniously contrived machines facilitated the study of its different modes of action: an unexpected discovery caused animated beings to feel the energy of that power which this fluid exerted upon them, by simple contact with the vessels wherein it was accumulated: finally, philosophers learnt that the luminous phenomena of electricity, which had been exhibited by way of amusement, were only an imitation, in miniature, of the explosions of a thunderstorm; and, to verify this remarkable analogy, Franklin discovered, in the influence of points, the secret equally surprising, of extracting the lightning itself from the

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* The name *electricity* has been borrowed from the word *electrum*, by which the ancients denoted *yellow amber*.

cloud which contained it in its bosom, and of presenting it to observation under the form and with all the characters of the fluid whose action is excited by our machines.

378. As the facts became multiplied in number, philosophers were more solicitous to explain them, and to trace their mutual dependence. Dufay recognised two different electricities; one of which he denominated *vitreous*, because it was produced by rubbing glass; the other he named *resinous*, because it was excited by rubbing resin and other analogous substances. He observed that substances animated by either species of electricity repelled one another, while they attracted those which possessed the other species of electricity. This idea, which was afterwards resorted to by Symmer, and reduced to the hypothesis of two fluids co-existing in the same body, was, if we may so call it, the key of the whole theory. Franklin exhibited the electrical actions in a different point of view, by his doctrine of positive and negative electricity, and made a very happy application to the experiment of the Leyden phial, the discharge of which he referred to a simple re-establishment of equilibrium. This mechanical manner of conceiving and illustrating a fact which then held the first rank among the wonders of electricity, drew a multitude of partisans to the philosopher of Philadelphia. Æpinus, one of the most distinguished of these, by applying the modern analysis to his doctrine rendered it more rigorous, and formed a more closely connected aggregate of all the observations previously known; he also discovered many facts worthy of attention, and thus yielded double service to the science, as a mathematician and as a philosopher. Indeed he was farther useful by preparing the way for Coulomb, who, commencing his progress at the point where Æpinus stopped, has alone surmounted numerous obstacles and described a new career. Provided with an apparatus of which he was the inventor, and which unites to the merit of simplicity that of an unexampled

precision, he has determined by decisive experiments, the law according to which electrical attractions and repulsions vary, at different distances; and this law he has found to be the same as that of universal gravitation discovered by Newton. The theory, established thus upon a solid basis, the same philosopher has applied to the manner in which the electric fluid divides itself between different bodies, and to the other effects which had been observed but not elucidated.

379. Such was the state of our knowledge respecting electricity, when the experiments of Galvani called the attention of all the learned in Europe, to phenomena very remarkable on account of their intimate connection with the motions of the animal economy, and which soon inspired an augmented interest by their relation with one of the most beautiful results of modern chemistry. The theory then needed a farther extension, that it might be applied to these new phenomena: and it was reserved to the celebrated Volta to give the necessary enlargement to the limits of the science, by the discovery of a principle which had eluded the sagacity of other philosophers.

1. *On the Electricity produced by Friction, or by Communication.*

General Notions.

Before we enter upon the developement of the theory, we shall lay down some preliminary notions, which it will be necessary to have always impressed upon the mind.

380. Bodies in general are distinguished into two classes, as they regard the communication of the electric

One class, which are named *conductors*, such as metals and liquids (with the exception of oil), transmit this fluid more or less easily to other bodies of the same class that are in contact with it. The others, which
non-conductors, such as glass, amber, sulphur,
k, &c., retain the fluid as if confined in their
hout permitting it to diffuse itself over the sur-
bodies.

W re to Grey and Wheeler the discovery of this
ence between bodies, relatively to the
ion of Electricity*. These two philosophers
that all bodies conducted indistinctly
l with the intention of propagating
it to a gre tance, they proposed to support a hempen cord which was to serve as the conductor upon a thin silk lace stretched out horizontally; expecting that this lace would only permit to escape a thread of electricity, proportional to the minuteness of its diameter, so that a great quantity of fluid would be transmitted by the hempen cord. This was about 80 feet long, and passed over the silk lace in such manner that one of its parts, being only a few feet long, descended vertically, having an ivory ball attached to its extremity. The other part was extended along a gallery in a horizontal direction till it reached a glass tube to which it was attached. While one of these philosophers rubbed the tube, the other saw some down from a feather placed under the ball attracted towards it, and then immediately repelled. But the silk lace being broken, Grey, who had no other at hand, substituted for it a metallic thread, and from that moment all the effects disappeared. Hence both philosophers inferred that the obstacle opposed by the silk lace to the loss of electricity, depended not upon the fineness of the strainer, but upon its very nature; and that which had been re-

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* Priestley's History of Electricity, vol. I. p. 55.

[illegible] an accident became a lucky one in the esti[illegible]a men of science.

[illegible]1. Non-conducting bodies have, moreover, this property, that when one among them is rubbed, it produces about it a disengagement of the electric fluid, susceptible of manifesting its presence. These bodies are distinguished by the name of *idio-electric bodies*, that is, *electrics per se;* and conducting bodies by the name of *anelectrics*, that is to say, *non electrics*, if it be not by communication.

382. It must not be disguised, however, that we still want a distinct line of separation between the two classes formed by bodies, in relation to the communication of the electric fluid. For there is no body which is either a perfect idio-electric, or a perfect conductor; and there exist between those that approach nearest to these two limits, an infinitude of intermediate ones which participate more or less of the idio-electric or of the conducting property. There is, also, a species of bodies in which the relation between the two properties varies very perceptibly, according to circumstances; and frequently that variation is occasioned by a mixture of conducting moleculæ, interposed between those of a body naturally idio-electric, or reciprocally. Thus, the atmospheric air, which supposing it very dry would possess the idio-electric property in a sufficiently high degree, is often charged with conducting aqueous vapours, which deprive it of that property in proportion to their abundance. For this reason it is that a humid air is so little favourable to electrical experiments; because by seizing the fluid disengaged about the apparatus, it prevents it from attaining that degree of accumulation on which depend both its energy and the success of experiments.

383. On the principles we have just been stating the construction of our electrical machines is founded. In that which is most in use at present, the electricity is produced by the friction exerted by several cushions

upon the two surfaces of a glass table or plate fixed upon an axis to which a rotation is communicated by means of a handle. The electric fluid, as it becomes disengaged, is attracted by points of iron situated horizontally at a small distance from one of the faces of the table, and from thence it diffuses itself over the surface of a copper cylinder, known more particularly by the name of *prime conductor*. This cylinder is supported by two columns of glass, a substance which being of a non-conducting nature, opposes itself to the dissipation of the fluid with which the conductor is charged; and the fluid not being permitted to escape otherwise than through the surrounding air, which by its nature refuses also to transmit it, becomes accumulated to a certain degree about the conductor; so that if we bring near it a finger, or any other body which is itself a conductor, the presence of the electric fluid is announced by a spark (*a*).

384. It is said of an electric body that it is *insulated*, when the body which sustains it opposes the propagation of the fluid with which it is charged.

(*a*) The advantages of this kind of machine are, its portability and the simplicity of its construction; so that any private gentleman after procuring a moderately thick plate from a glass-house, may construct one for his own use with the assistance of a common cabinet-maker: the conductor may, in such case, be insulated by resin, wax, silk, or any other non-conducting substance.

These plate machines when of a large diameter are by far the most powerful of any; and their energy is greatly increased by a second plate parallel to the former, and turning on the same axis. A very powerful machine of this kind was made in England by Mr. John Cuthbertson for the Teylerean museum at Haarlem. It consisted of two circular plates of nearly 5½ feet diameter, about 7½ inches asunder, and each excited by four rubbers. The prime conductor was divided into two branches, so contrived as to enter between the plates, and by means of points collect the electric fluid. Such machines, however, with two large plates, require much labour to turn them, and are more liable to accidents than the common cylinder machines, sold by most philosophical instrument-makers. Next to Cuthbertson's, those by Adams, Nairne, and Jones, are generally most esteemed. Tr.

385. We must not omit to mention, that a conducting body, when it is insulated, acquires the electric property by the friction of a non conductor. But the fluid with which it becomes charged is, in this case, furnished by the rubber; so that the conductor does nothing else than receive it by communication. When the same body, not insulated, undergoes in like manner the friction of a non conductor, it also disengages the fluid which is taken up by the first body, but transmits it immediately to the surrounding bodies with which it is in communication.

386. The hypothesis which we shall employ to explain these phenomena, will lead us to consider with Symmer*, the electric fluid as composed of two different fluids, which are neutralised one by the other in the ordinary state of bodies, and which are disengaged when the bodies exhibit signs of electricity. It must be acknowledged, however, that the existence of these two fluids is not founded upon such satisfactory reasons as that of the electric fluid itself, which we here suppose to result from their combination. But the adoption of these fluids conduces, notwithstanding, to a simple and plausible manner of representing the results of experience, and preserves us from the difficulties into which we shall see that we are likely to fall by attempting any other hypothesis (*b*).

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* Philosophical Transac. vol. LXI, part i. pa. 340, et seq.

(*b*) Professor Robison states a fact which he considers as a complete proof that the doctrine of vitreous and resinous electricity is unfounded: both kinds of electricity are produced in a conducting body, without any material communication, by mere juxta-position to a body possessed of either the vitreous or the resinous electricity. For our own parts, we hesitate to admit the existence of the electric fluid itself, as completely established; or if we admit it in theory, we do not positively affirm that it exists in nature, conforming in this respect to what M. Haüy has stated generally in par. 118. But it is of comparatively little importance, whether one fluid, or two component fluids really exist, or be merely hypothetical, provided the assumed hypothesis enables us faithfully and satisfactorily to exhibit and connect the results of experiment. Tr.

Such, in general, is the manner of acting of the two fluids now spoken of, that the moleculæ of each mutually repel one another, while they attract those of the other fluid. Hence there results four different combinations of actions between the fluids of two bodies, namely, two repulsions and two attractions; and on these depend the motions by which the bodies themselves approach or recede one with regard to the other, as we shall soon shew more at large.

387. The electric fluid is diffused in all bodies. The terrestrial globe is its inexhaustible source; on which account this globe is often called the *common reservoir*, when we speak of its intervention in electrical phenomena. Every body possesses a certain quantity of the same fluid, which depends upon its nature, and which we shall therefore call, *the natural quantity of fluid* of that body. If through the effect of any circumstance, this fluid undergoes a decomposition, the body will be found electrised or electrified: whence it is evident that we must not confound a body in its natural state with a body that merely has its natural quantity of fluid; since the decomposition of this fluid may cause the body to pass from its natural state, without any addition of extraneous fluid. But the body may likewise pass to the electric state, in virtue of a superabundant quantity of either of the constituent fluids, which it shall have received by communication.

388. Let us now compare the opinion of Franklin as to the electrisation of bodies, with the manner of conceiving the same phenomenon in the hypothesis we have adopted. This celebrated philosopher considered the electric fluid as a simple substance; and in the passage to the state of electricity one of two things might happen: the body might receive from without a quantity of fluid which would become added to the natural quantity, and in this case, we should say of this body that it was electrified *positively*; which takes place with regard to glass,

and to many other substances, in consequence of friction: or the body might lose a portion of its natural fluid, and then it would be found electrified *negatively*; this would be the case with sealing wax, resin, silk, &c. when they are rubbed. Hence are deduced the expressions of *positive* and *negative electricity*, employed by Franklin to represent the two opposite states of which we have been treating: we shall soon see that the same body might also, according to circumstances, pass to one or other of these states.

But, in the hypothesis we have adopted, all the effects attributed by Franklin to positive electricity, or to the superabundance of a simple fluid admitted by that philosopher, would be produced by the action of the two constituent fluids, restored to its free state; and the effects, which in his views would depend upon the negative electricity, or the subtraction of a part of the fluid, would be due to the action of the other constituent fluid. We shall, therefore, call the fluid that relates to the first kind of electricity, the *fluid of vitreous electricity*, or simply the *vitreous fluid*; and we shall give to the fluid which produces the other kind of electricity, the name of *fluid of resinous electricity*, or for conciseness the *resinous fluid*. This language is nearly the same as was employed by Dufay, in a less determinate sense; and since we possess but little knowledge as to the real nature of these two fluids, whose existence indeed is not completely demonstrated, we conceive we cannot do better than borrow the names of those bodies which appear to furnish them in a more especial manner.

389. We must premise that the two fluids assumed here ought not to be confounded with the two currents, one of effluent and the other of affluent matter, which Nollet had devised to account for electrical phenomena. Those two currents appertained to the same fluid, and proceeded, the one from the conductor towards the surrounding bodies, the other from them towards it. There is, doubtless, a wide difference between such hy-

potheses, which employed effluvia whose actions freed from all law, and from every rigorous method, lead only to vague explanations of *part* of the phenomena, while they are defective in their application to others; and those theories that are founded upon forces whose measures are deduced from experiment, and whose different effects are determined by computation with a precision which would enable us to predict them.

390. Two idio-electric bodies excite in one another, by their mutual friction, two different states of electricity; and the circumstances that determine either of them to acquire in preference one kind of electricity, depend upon certain causes which it is not always easy to discover. Glass and substances in which the vitreous character is clearly marked, such as rock-crystal and gems, almost always acquire vitreous electricity, whatever may be the rubber employed: we say, *almost* always; for we have observed that glass rubbed with the hair of a cat becomes electrified resinously. On the other hand, resin, sulphur, sealing-wax, &c., would acquire resinous electricity, on being rubbed with any idio-electric whatever. But here there is a restriction to make, at least in regard to vitreous substances, which only manifest vitreous electricity after they have been rubbed, when their surface is smoothly polished. Thus glass which has been roughened becomes resinously electrified, by friction with the same substances which had previously communicated to it vitreous electricity. In general, *cæteris paribus*, substances that have their surfaces set with asperities, appear to have a more decided tendency towards resinous electricity. When we rub a white silk ribband against another of black silk, the first becomes electrised vitreously and the second resinously; which Ingen-Housz ascribed to the colouring matter of the dark ribband being composed of such moleculæ as give a certain roughness to its surface.*

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* Nouvelles Exper. et Observ. sur divers objets de Physique, t. I. p. 5.

Among insulated metallic bodies which are rubbed with a substance of a determinate nature, such as a piece of woollen cloth; some, for example, zinc and bismuth, acquire vitreous electricity; and others, as pewter and antimony, acquire resinous electricity. We mention these metals in preference, being those which most commonly give the same results. For singular anomalies are observed in experiments of this kind; such that the same piece of metal, placed in similar circumstances, shall sometimes acquire a different electricity from that it had formerly manifested.

The same diversity obtains with respect to certain idio-electric bodies. Sometimes it is remarked that friction gives birth constantly to one kind of electricity in a certain piece of a substance, while it as constantly produces a different kind in another piece, otherwise similar to the former. We know of no body in which this sort of anomaly results from such delicate and imperceptible shades, as in the mineral commonly called *cyanite*, and which we have named *disthène* (having two virtues (*c*). Among the various crystals of this mineral, some always acquired resinous electricity, by means of friction, and others vitreous electricity: in some of these, the two species of electricity were respectively contrasted upon two opposite faces; while neither the eye nor the touch could discern, in either the lustre or the polish of those faces, the slightest indication of that difference of states (*d*).

(*c*) This stone was first described by the younger Saussure, under the name of *sappare*. The name *cyanite* which was given it by Werner, was suggested by its milk white colour with shades of sky or prussian blue. The primitive form of its crystals is a four-sided oblique prism, those sides being inclined at an angle of 103°. Cyanite has been analysed by Saussure, Struvius, and Hermann, all of whom agree, as to the ingredients, namely, alumina, magnesia, silica, iron, and lime; but they differ widely as to the relative proportions of those ingredients: Saussure found more than half to be alumina, Struvius more than half silica, and Hermann found 39—97ths of magnesia. Tr.

(*d*) The comparatively recent discovery of electricity by simple contact

Electricity.

efore we enter upon the developement of the
will be necessary to present an idea of *electric*
t We give this name to the repulsive force with
which the particles of the vitreous or of the resinous fluid
d ver the surface of a body tend to separate from
er. This force is proportional to the density of
the f or to the number of moleculæ comprised in a
t ice. Let us suppose that two bodies were
en for example, with a vitreous electricity. If we
ot each body a little metallic disc,
xed to the extremity of a needle of gum lac, to keep it
ntities of fluid which the two discs (sup-
equal) would take up from these bodies,
wou ely as the tensions of the bodies; and

deserves some notice in this place. Volta traced this singular property in heterogeneous metals, and it enabled him to explain the phenomena of the pile: See his letter to Sir Joseph Banks, in Phil. Trans. for 1800, pa. 403. But Libes has pursued this branch of the enquiry farther than any other philosopher whose works we are acquainted with. He has made numerous experiments in regard to the electricity developed by the contact of resinous bodies with metallic substances, of resinous bodies with vitreous and calcareous substances; of resinous bodies with animal and vegetable substances; and has shewn clearly that the phenomena exhibited in all those experiments was due to the contact exclusively. The inferences he draws from his researches are, 1st. That resins exert at contact, a *vis electromotrix* more or less powerful upon all the bodies in nature. 2dly. That the electricity developed by the contact is always the reverse of that generated by friction. 3dly. That to establish the existence of metallic electricity it is dangerous to employ resinous condensers; for the powerful action of the resin upon the metal might combine itself with that exercised by the heterogeneous metals one upon the other, and thus contribute to the production of phenomena.

M. Libes likewise deduces from his experiments a method previously unknown, of always electrising positively or vitreously resinous substances, and of always electrising negatively or resinously polished glass, siliceous, calcareous and metallic substances, &c. The instrument used for this purpose, he calls *électromoteur résineux:* it is composed, 1st, of a disc of wood well polished, and covered with one, or better still, with several cases of taffeta, varnished with elastic resin: 2dly, of a disc of metal, of polished glass, of agate, or of marble, &c., insulated by a cylinder of glass or of sealing wax, fixed to each disc. For the more particular description of this instrument, and its use in electrical experiments, the reader may consult Libes's Dictionary, vol. I. Tr.

by employing to measure them, methods of which we shall speak in the sequel, the relation between the tensions may be ascertained.

On the Law regulating Electrical Actions at different Distances.

392. The forces of the two fluids that compose the electric fluid, act, as we have already stated (378) in the inverse ratio of the squares of the distances. This law had already been adverted to by many philosophers, and particularly by Æpinus, who said that, if he were to choose he should give the preference to this law, because it had general analogy in its favour*. Hence we see how far he presumed that the principle of the celestial motions was extended to all actions at a distance; and the more this idea was beautiful and gratifying to the mind, the more it was to be desired that it might become completely verified.

Coulomb has demonstrated it at the same time, both for electrical actions and for those that depend upon magnetism. He has given to the apparatus which he used in the experiments relative to electricity, the name of *electrical balance*, which is extremely appropriate, since it furnishes the means of establishing the equilibrium between an electric force and another force whose smallest quantities are susceptible of being measured with much precision.

This latter force is denominated the *force of torsion*. It is the effort made by a thread which has been twisted to untwist itself and return to its former state. Let *a c* (fig. 33. Pl. V.) be a thread or wire of metal or any other matter to which a small lever *b d* is suspended by its middle; let us suppose that this lever being first

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[*] Tentamen theoriæ Electric. et Magnet., p. 38.

in a state of quiescence, begins to turn about the point *c*, by describing circular arcs with its two extremities. The thread becomes twisted at the same time by a number of degrees equal to that which is comprised in each of those arcs; and if we would retain it in this state of torsion, we must apply to one or other of the extremities *b d*, of the lever, a resistance which will counterbalance the effort of the thread to return to that point where, the lever being immoveable, the torsion would be nothing. Now Coulomb has proved that, all other things being equal, the effort which he names *force of torsion* is proportional to the angle of torsion: let us imagine, for example, that in the case we have been speaking of, the arc described by the point *b*, or by *d*, or which comes to the same, the quantity of torsion was 30°, and let us denote by *r* the resistance capable of making an equilibrium to that torsion; then, if we suppose a double torsion, or an arc of 60° described, it will be necessary, in order that there should again be an equilibrium, to employ a resistance equivalent to $2r$.

393. The apparatus contrived by Coulomb is composed principally of a large glass cage ACDB* (fig. 34.), covered with a large plate AC of the same substance. Upon the middle of this plate is soldered a vertical tube *f e b h*, likewise of glass, and surmounted by a much shorter tube or collar of brass *c b h d*, in which another tube of the same metal turns with friction. The latter carries a plate *l y* having an orifice at its centre to receive a little stem or pivot, on which is fixed an index *o l* that is made to turn at the same time with the pivot. The rim of the plate *l y* is divided into 360 degrees, in the order of *l k y*. The pivot carries at its inferior extremity a little pincer

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* We may give to this cage either a cylindrical form, such as that represented in the figure, or a cubical form, at pleasure.

which holds a very thin silver thread *p n*, at whose bottom is suspended a little brass cylinder *n u* to keep it stretched. This cylinder is split in the direction of its length, and performs the office of pincers to press and retain the little lever *a g*, one of whose arms, namely *n a*, is made of a silk thread varnished with gum-lac, and terminated by a little circular plane *a* of gilt paper. The other arm is a copper wire *n g*, of such a length as ensures the horizontal position of the lever. Now, it is in the torsion impressed upon the metallic thread or wire *p n* that the force consists which serves to measure that of the electric bodies whose effect it balances.

The plate AC has another orifice at *m*, through which passes a second silk thread, varnished also with gum-lac, and maintained in the direction *m t*, nearly vertical, by means of a stick *r s* of sealing wax. This silk thread sustains at its inferior extremity a ball *x*, which corresponds to the point *zero* of a graduated circle *z q* fixed or marked on the outside of the cage ACDB. We may always, by means of the superior brass tube, which we can turn without difficulty in the collar within which it is fitted, dispose things in such a manner that the little circular plane *a* shall touch the ball *x*, without obliging the thread of suspension *p n* to experience any torsion *(e)*.

Things being supposed in this state, we shall proceed to describe the experiments made by Coulomb before the Academy of Sciences, in 1785. This philosopher first electrified the gilt circle *a*, and the brass ball *x*, by touching them with a little conductor charged with vitreous electricity, which he introduced into the cage by an aperture formed for that purpose. Immediately the ball repelled the little circular plane to

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(e) The honourable Mr. Cavendish has employed a nearly similar construction to this of Coulomb's, in his valuable experiments relative to the force of gravity. Phil. Trans. 1798, part II. Tr.

the distance of 36°, estimated from the position of that plane with regard to the circumference described upon the glass cage, By a necessary consequence the metallic wire was twisted an equal number of degrees. Coulomb continued the torsion by a farther quantity equal to 126°, by turning the index *o l* attached to the pivot which held the thread suspended; and it will be easy to conceive that, in this case, the rotatory motion of the index ought to be in a direction contrary to that in which the gilt circle had moved,

The force of torsion was then found to be considerably augmented, and the repulsive action of the two bodies being no longer sufficient to balance it at such a distance, the gilt circle returned again towards the ball until it reached the point where the repulsive force had so increased in consequence of the diminution of distance that the equilibrium was re-established: at that moment the distance between the bodies was only 18°.

Now it must be remarked that the impressed torsion of 126°, being a continuation of the torsion of 36° previously produced by the repulsion of the two bodies, if we subtract from this latter the 18° through which the thread had untwisted itself while the gilt circle returned towards the brass ball, there will remain 18°, which, added to the 126° of torsion impressed will give 144° for the total torsion relatively to the second position of the two bodies. But the torsion which had place in the preceding position was of 36°; whence it resulted that the two repulsive forces which made the equilibrium with these two torsions, were in the ratio of 144 to 36, or that of 4 to 1. Now the corresponding distances were 18 and 36, or as 1 to 2: from which it appears that the repulsive forces conformed to the inverse ratio of the squares of the distances.

This experiment was varied in several different ways, according to other relations between the distances; and all the results were found conformable to the same law.

The small errors inseparable from the results furnished by a machine whose movements always leave something in abatement of geometrical precision, have not escaped the attention of Coulomb: for example, the true measure of the distance between the two bodies is not precisely the arc intercepted between them, but the cord of that arc. On the other hand, the repulsive action of the brass ball upon the gilt circle is a little oblique upon the lever which carries that circle. Yet the machine is so ingeniously contructed, that the two errors proceed in contrary directions, in such manner as to compensate very nearly when the angles are not considerable.

Analagous experiments have proved that the electrical attractions conform, in like manner, to the inverse ratio of the square of the distance : and besides, we may here, without having recourse to observation, immediately infer the law of the attractions from that of the repulsions, by considering the equilibrium of two bodies, each of which has only its natural fluid. For, since the quantities of vitreous electricity which make part of the quantity of the natural fluid are always proportional to the quantities of resinous electricity; whenever the mutual repulsions of the same kind of fluids are in the inverse ratio of the squares of the distances, the attractions must necessarily follow the same law, as without it the equilibrium cannot obtain.

394. The law we have thus established leads to a very remarkable result with regard to the electricity of conducting bodies. It is this: all the free fluid which appertains to one of those bodies in the electric state, is diffused about its surface, while there exists no sensible portion within the body. This property is demonstrated equally by reasoning and by experiment; and we shall present in succession both kinds of proof,

observing, notwithstanding, that the geometrical demonstration is only rigorous for spherical bodies, and a few others of which we shall speak presently. But as a solid of any form may always be considered as circumscribing one of those alluded to, the manner in which the principal action is modified by the redundant matter, can only produce a very slight difference in the result.

The demonstration which we shall exhibit of this result, considered in relation to spherical bodies, depends upon two principles of the Newtonian philosophy. One of them, which we have before spoken of when treating of attraction (53), is this: if all the moleculæ of a sphere attract inversely as the squares of the distances (and we must of necessity say the same of the repulsive force), the sum of the actions which they exercise upon a particle of matter placed out of the sphere, will be the same as if all the acting moleculæ were concentrated in the centre of that sphere. In this case, such, as we have remarked, is the manner in which the actions emanating from different points of the sphere are mutually combined, that there is a compensation between the weaker actions of the moleculæ placed beyond the centre, with respect to the particle attracted or repelled, and the stronger actions of the moleculæ situated nearer than the same centre; so that the centre is the point in which we must ultimately conceive all the moleculæ to be united, to exercise a mean force which should be equal to the aggregate of all the forces disseminated through the entire mass.

This principle only obtains in consequence of the circumstance that each of the concentric spherical laminæ of which we may suppose the globe to be constituted from the centre to the surface, itself attracts or repels, as if all its matter were condensed into the centre; in such manner that the proposition is equally true of a simple spherical shell or envelope which should leave a complete vacuity between it and the centre.

In the other principle we suppose a like envelope, whose moleculæ still act according to the same law: but the particle attracted or repelled, instead of being imagined out of that envelope, is situated somewhere within its cavity; and we prove that, in such case, it is attracted or repelled equally on all sides, or, in other words, that it remains immoveable in its position: this is demonstrated by Newton in a remarkably simple manner * (*f*) by the aid of the following construction.

Let *onrs* (fig. 35. Pl. VI.) be the projection of the envelope or shell under consideration, and let *m* be the particle attracted; we shall suppose that the envelope acts by attraction upon that particle, since the same demonstration applies equally to the hypothesis of a repulsive force. Draw through *m* two lines *bmc*, *gma*, to intercept upon the envelope two infinitely small arcs *ab*, *cg*, such as may be taken for their cords. Let us then conceive two similar and infinitely small portions of the shell which have *ab* and *cg* for diameters: they will be respectively as the squares of those dia-

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* Philosophiæ Natur. Princip. Mathemat., t. I. sect. XII. prop. lxx. theor. xxx.

(*f*) Much of the reasoning in this part of the work is extremely similar to that of the Hon. Mr. Cavendish in his curious dissertation in the Philosophical Transactions, vol. 61. The differences being no more than are required in such modifications as would render the demonstration of the English philosopher applicable to the theory of Coulomb.

Mr. Cavendish has given his various theorems on the action of spheres and circular plates, in an abstract and general mathematical form, applicable to any law of electric action which may be warranted by experience; and of course it was easy to accommodate them to the inverse duplicate ratio of the distances, as well as to apply them to Coulomb's hypothesis instead of that of Æpinus.

We are the more surprised at M. Haüy's omission of Mr. Cavendish's name, not merely here but throughout his Treatise on Electricity, as it appears from what he says at par. 226., that he is not a stranger to the merits of our learned and ingenious countryman in other respects. Tr.

meters; and since the attractions conform to the direct ratio of the masses and the inverse ratio of the squares of the distances conjointly, they will be as $\frac{(ab)^2}{(mb)^2}$ to $\frac{(cg)^2}{(mg)^2}$. But, because of the similar triangles mab, mcg, we have $ab : cg :: mb : mg$, or $(ab)^2 : (cg)^2 :: (mb)^2 : (mg)^2$. Therefore $\frac{(ab)^2}{(mb)^2} = \frac{(cg)^2}{(mg)^2}$, that is to say, the attractions are equal. Now, if we suppose the envelope divided into an infinitude of minute portions similar to the preceding the attractions of every two respectively situated on the opposite sides will be also equal whence it follows, that the particle m, being no more solicited towards one side than towards the other, will remain immoveable.

Such, therefore, is the combination of actions produced by the moleculæ of the shell, that if we conceive a plane tr to pass through the particle attracted or repelled, and to cut the envelope into two parts necessarily unequal, the actions of the smaller part tgr being in general nearer, while those of the greater tar are exerted at more considerable distances, there will result an exact compensation which will retain in equilibrio the particle subjected to those contrary actions.

395. All this being well understood, let there be given a conducting body of a spherical figure, and filled with a freely acting fluid of either vitreous or resinous electricity; and let us suppose that, if it were possible, there should be an equilibrium. It will follow from the preceding principles that this equilibrium cannot subsist a single instant, and that all the fluid will be driven out of the sphere.

Let os (fig. 36) represent the sphere in question: let us separate the fluid, mentally, into an infinitude of concentric spherical laminæ infinitely thin, enclosing one another successively from the centre to the surface, as shewn in the figure; and let us consider the action of the sphere upon a particle *m* situated at the exterior surface of any one of those laminæ, as *d e n*. The repulsion of all the fluid contained in this shell and in all the others that are nearer the centre, will be the same as that of a sphere upon a particle placed at its surface. Hence, in consequence of the first principle, this particle and all those which are at the same distance from the centre will tend to fly off from one another, and to quit the sphere. There cannot, therefore, be any other obstacle to this tendency than on the part of the laminæ comprised between the particle *m* and the exterior surface *o s*. But the second principle tells us that the actions of those superposed and concentric laminæ annihilate each other, with regard to a particle placed nearer the centre; and consequently the action which is exerted from the centre towards the surface will subsist entire.

As the fluid issues from the sphere there will be formed about the middle of that sphere a vacuity which will itself have the spherical form. Every particle situated in one of the intermediate shells between that vacuity and the exterior shell will be, with respect to the shells situated below it, in the case of a particle placed at the surface of a hollow sphere, and it will be, with regard to the shells situated above it, in the case of a particle situated just within a hollow sphere; whence we see that the action of the former shells will continue to solicit it to go farther from the centre, while the action of the other shells to prevent it will be evanescent: thus all the fluid which occupied the sphere at first will quit it; and it would diffuse itself indefinitely in space, if it were not arrested in its progress by the contact of the surrounding air, which, being of an idio-electric nature, will refuse to unite with it, and will hold it applied and condensed, about the sphere under the form of a very thin envelope.

Since the equilibrium could not subsist primarily; it cannot establish itself afterwards; and hence there is not, with regard to a free fluid appertaining to a conducting body, any other manner of distributing itself that accords with the law of repulsion of the moleculæ, than that of diffusion over the surface of the body.

Experiments may be adduced to support this theory. You take a hollow metallic sphere, in which there is made a circular orifice of 2 or 3 centimetres (about $\frac{4}{5}$ or $\frac{6}{5}$ of an inch) in breadth, and after having placed it upon an insulator, or insulated stool, you make it communicate with a conductor which you electrify. You may even, to avoid the suspicion of favouring more the interior surface, which ought not, according to the theory, to give any sign of electricity, establish a communication between that surface and the conductor. Having afterwards withdrawn the sphere, always carried upon its insulator, you apply to a point of its interior surface a little circle made of a sheet of metal, and fixed at the extremity of a long needle of gum-lac. You present this circle to a very sensible electrometer which remains immoveable. Then you apply the same circle to a point of the exterior surface of the sphere, and that circle presented anew to the electrometer, produces therein a very manifest motion; and if this electrometer be already electrified, it will indicate an electricity in the little circle, of the same kind as that of the conductor which served to electrify the sphere.

You must be careful to introduce the metallic circle into the sphere and to withdraw it as quickly as possible, and to make it pass through the middle of the orifice, to prevent its taking up any portion of the electricity which is accumulated about the borders of that orifice. It may happen, even with those precautions, that this electricity may communicate one of the contrary species to the needle of gum-lac which remains insulated with regard to the aperture, during the short period that the metallic circle is within the sphere. But we may assure ourselves that the electricity in question appertains to the gum-lac, because it continues to be sensible to the electrometer when the metallic circle has been touched with the hand.

The point of the theory we have just been considering, has become, in the hands of the celebrated Laplace, the subject of an elegant application of the formula which that philosopher employed in determining the figure of the earth. It consists in this, that the result given by a body of a spherical figure, is equally true for all the ellipsoids of revolution; so that the electric fluid ought also to carry itself entirely to the surface of such solids. The same calculus likewise leads to this remarkable consequence, that the repulsive force, or the tension of the fluid corresponding to the pole of the ellipsoid, is to that of the fluid which covers the equator, as the diameter of such equator is to the polar axis: whence it follows that if the ellipsoid be probate, the tension will be stronger at the equator than at the pole. Biot has extended these results to all spheroids differing but little from a sphere, whatever be the irregularity of their figure*.

On the Manner in which the Electric Fluid distributes itself among Bodies in contact with one another.

396. In all that we have been saying we have considered the body which was at first supposed filled with

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* See the accurate exposition which this able geometer has given of the same results in the *Leçons de l'Ecole Normale*, new edit., vol. VII. pa. 85. et seq. He has also elucidated the method of submitting them to the calculus in the *Bulletin des Sciences de la Société Philomat.* 8 Prairial an. ix. pa. 21, et seq.

electric fluid, as not exercising any attraction upon that fluid, either to prevent it from escaping, or afterwards to balance the resistance opposed by the air to its dissipation, when it envelopes the body. This conducts us to a new result which is closely connected with the preceding. We have said (387) that every body possesses, of itself, a certain quantity of electric fluid, composed of the vitreous and resinous fluids. This quantity, which depends upon the nature of the body, remains as though enchained in its interior, so long as the two fluids are neutralised one by the other. But as soon as they become disengaged, they lose their tendency to continue in the body, and only obey their mutual repulsive force. How come they afterwards to reunite afresh? The compound fluid which results from their assemblage re-enters the body, and there becomes fixed as before. In like manner if a body should receive besides an additional portion of the vitreous or resinous fluid, this will diffuse itself over the surface of the body without penetrating to the interior, and it is even held to this surface only by the intermediation of the surrounding air which refuses to transmit it. We shall, when speaking of electricity in a vacuum, cite an experiment which confirms this theory.

397. Since the free electric fluid of a body does not appear to have any affinity for it, it will be equally indifferent with regard to any body whatever: so that if we bring an electrified conducting body into contact with another which is in the natural state, the part which the former will communicate to the latter of its free fluid will depend solely upon the form of the two bodies, and not at all upon their nature. This has been proved in the most unequivocal manner by Coulomb, by the aid of the following experiment. Electrise the brass ball *x* (fig. 34.), placed as we have said (393) in the glass cage A C D B; and, after it has repelled the gilt circle *a*, augment the torsion by a certain number

of degrees, and determine the total torsion, as well as the resulting distance between the ball *x* and the circle *a*. Immediately touch the brass ball by another of the same diameter but of different matter, of pith of the elder tree, for example. As soon as the latter is withdrawn the gilt circle places itself at a less distance from the brass ball, which has lost a part of its fluid and at the same time of its repulsive force. Slacken the torsion till the circle is brought back to the same distance, and it will be found that, in this case, the torsion is no more than the half of that which it was the first time. Therefore the repulsive force is diminished a half. Now the electrical actions follow the direct ratio of the masses (which are here the quantities of the fluid,) and the inverse ratio of the squares of the distances; and since the distances are equal, those distances are simply as the quantities of fluid: whence it results that, in the second case, the copper ball possesses only the half of its fluid; so that the primitive quantity was divided equally between this ball and that of elder-pith, because of the equality and similitude of the two bodies.

Thus, in the communication of electricity, the surfaces of bodies merely serve in some sort as receptacles of electric fluid, which seems to exist there in a passive state, and to remain only so long as there is resistance from the surrounding air. But though the nature of bodies contributes nothing to the ratio according to which the electric fluid is distributed among them, it influences the time which the separation requires, in such manner that the conducting faculties vary according to the different qualities of the substances. Metals, for instance, transmit the fluid much more rapidly than wood and paper; and in this respect, as in many others, the mode of action of the electric fluid approaches that of caloric. If, therefore, an electrised conducting body be put in contact with a second body likewise a conductor, which is in its natural state, there will be a term, in the transmission of the fluid from one to the other, beyond which the former will cease to communicate and the latter to receive; and this limit will be more or less distant, according as the body that receives the fluid shall be more or less susceptible of conducting it. But the difference only affects the duration of the communication, which will always be made without any preference for one body rather than for another, as to the quantity of fluid communicated or received.

398. It was natural, in proving experimentally this defect of affinity of the electric fluid with regard to different bodies, to select the most simple case, which is that where the bodies, being similar in their form, are moreover equal in surface. But Coulomb, after having established in this manner the principle under consideration, extended his researches to bodies whose surfaces were different, always supposing however that the shape was spherical. That the results at which he arrived may be the better comprehended, it must be considered that when a globe which is in its natural state is brought into contact with another globe that is electrified, the first has scarcely attained the electric state itself when the two fluids exert one upon another their repulsive force, and impel each other mutually towards the parts opposite the point of contact, so that the electric density is nothing in that point and in the surrounding part to a certain distance. Afterwards when the globes are separated, their respective fluids diffuse themselves uniformly about them, and the quantities of those fluids are found equal when the surfaces of the spheres are equal also.* But if the surfaces are unequal, in any given ratio, it then happens that the quantities of fluid vary in a different ratio which is less than that of the surfaces: for those quantities are determined from the conditions of equilibrium which shall

be established between the forces of the two fluids, at the moment of contact; and this equilibrium requires that the ratio between the quantity of fluid of the smaller globe and that of the larger, shall so far surpass that which exists between the surfaces, that its excess may compensate for what was lost by the first globe, on account of a less extended surface. Thus Coulomb has ascertained experimentally, that when the surface of the smaller globe was nearly $\frac{1}{15}$ of that of the larger, its quantity of fluid was about $\frac{1}{11}$.

From these results it is easy to determine the law of variation of the electric densities in bodies between which the fluid was distributed, or, in other words, the quotients of the quantities of fluid divided by the surfaces. Coulomb has found that for two globes, one of which remains the same, while the other is chosen constantly smaller and smaller, the ratio between the electric densities augments according to a progression whose successive terms are continually diminishing, and has for its limit the ratio of 2 to 1, in such manner that in the case of that limit the second globe must be supposed infinitely small *(g)*.

(*g*) When the bodies did not differ greatly in magnitude, he determined this by the immediate application of them to his electrometer (par. 398.); but when one was extremely small in comparison with the other, he first determined the force of the large body, and then touched it 20 or 40 times with the small one, till the force of the large body was reduced to $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, &c. The general result was, that when the surfaces of the spheres had the proportion expressed in the first column of the following table, then the density in the small one had the proportion expressed by the numbers of the second column, and never attained the magnitude 2.

1	1.
4	1·08.
16	1·3.
64	1·65.
Infinite	2.

This is widely different from the proportions which obtain when the two spheres communicate by very long slender canals; which were found exactly conformable to the determinations of the theory, and indeed to the deductions of Mr. Cavendish in the Phil. Trans. for 1771: but in

399. In his experiments of another kind Coulomb disposed upon the same line, a certain number of globes covered each with a sheet of metal (as tin foil), and in contact one with another; and he investigated the laws according to which the fluid would distribute itself among those different bodies, so that their forces should be in equilibrio. He has thus employed as many as 24 globes, all of equal diameter. It is easy to conceive at the first glance, that, supposing all these globes electrified, there will be an equality between the tensions or electric densities of the two extreme globes; and that, in like manner, the densities of any two globes equally distant from the extremes are equal respectively. It is obvious also, that the density of each extreme globe ought to be more considerable than that of the follow-

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Coulomb's experiments the spheres touched each other, and had no other communication.

With regard to the distribution of the electric fluids among several unequal globes, some of Coulomb's experiments and results are as below.

He placed two globes each of two inches diameter in a line with a globe of eight inches diameter, the two smaller ones being in contact, and one of them with the larger: he found that the quantity of electricity of the smaller globe most distant from the greater, was to that of the nearest, as 2·54 to 1.

Four globes of two inches being placed in a row successively in contact with each other and with a globe of eight inches diameter, the ratio of the quantities of electricity taken by the smaller globe farthest from the larger, and that which was nearest, was found to be 3·40 to 1.

Having placed 24 globes each of two inches diameter, in a like series with the larger globe, Coulomb compared the twenty-fourth little globe, that is to say, the last in the row, with others in the same row, and these were the results:

The electricity of the twenty-fourth was to that of the twenty-third, as 1·49 to 1; to that of the twelfth as 1·70 to 1; to that of the tenth as 2·1[illegible] to 1; and to that of the first, which was in contact with the larger globe, as 3·72 to 1. Lastly, the electricity of the twenty-fourth was to that of the larger globe, as 2,16 to 1.

All these results are perfectly consistent with the two principles, that the electric fluid does not penetrate bodies, but solely pervades their surface, and that the electric forces act in the inverse ratio of the squares of the distances. Tr.

ing ones, since it alone sustains in equilibrio all the others, while the second, for example, is aided by the first in balancing the action of all those which are behind it. Now, such is the law conformably to which the densities decrease, estimating from the extreme globes, that the diminution is very rapid in regard to the globes near the extremes, as the second and third from each end, and that afterwards the densities diminish more and more slowly to the middle of the row, where the density is nothing. This inequality between the forces of the different globes is a consequence of the inverse ratio of the squares of the distances, which determines the quantity of fluid requisite for each globe, that its action may be in equilibrio with that of all the others.

Coulomb has deduced from the preceding results, the mode in which the electric fluid is distributed over different points of the surface of a cylinder. It varies from the extremity to the middle nearly in the same manner as upon a row of equal globes; and this resemblance arises from the circumstance that the fluid is disposed about different globes under the form of zones, between the points of contact, after which the density is next to nothing unto a certain distance, because of the great repulsive force acting at those places; but, at the first and last globe the fluid envelopes the hemisphere opposite to the contact with the nearest globe: therefore, to complete the relation of the distribution of the fluid, to that which obtains upon the cylinder, the surface of this latter body may be considered as constituted of a series of annular bands comprised between two hemispheres.

In proportion as longer and more slender cylinders are employed, the electric density of the points situated towards the extremities will augment with respect to that of the intermediate points: and if we imagine a very thin cylinder to be fixed upon a large electrified globe, whose action will favour still more the augmentation of density which ought to have place at the opposite extremity; then, since the force of the fluid situated at this extremity must necessarily be in equilibrio with that of all the rest of the fluid diffused both over the cylinder and over the globe, the density may become so considerable as to prevail over the resistance opposed by the air to the transmission of electricity: it is from this consideration that Coulomb elucidates the influence of bodies terminated by points to transmit the electric fluid rapidly. The explanation we shall adopt because it is more susceptible of being developed by perspicuous reasoning, is only a different manner of conceiving the same combination of actions.

The Law according to which Idio-Electric Bodies gradually lose their Electricity.

400. There is, in the respects we have been considering, a very complete difference between Idio-electrics, and conducting bodies. When the natural fluid of the latter comes to be decomposed, by the action of causes of which we shall speak presently, its two principles immediately diffuse themselves over the exterior surface. We shall soon understand, on the contrary, that when the body is idio-electric, the two constituent principles remain in its interior, even after their disengagement, and distribute themselves, by contrary motions, in two opposite parts of such body. These motions, however, are not executed without a certain difficulty, which is occasioned by the resistance of the proper moleculæ of the body; so that when the cause which had decomposed the fluid ceases to act, the re-union of the two principles which brings back the body to the natural state, is only accomplished, in like manner, with a certain tardiness. This resistance opposed by

an idio-electric to the motion of the fluid within it has been compared to friction, and it has been denominated the *coercive or restraining force*. The effects of this force are most remarkable in bodies which become electrised by heat, as we shall see in the sequel.

It should be added, that what we have been saying is on the supposition that the substance of bodies exists in all its purity, unmixed with extraneous matter. But it is most frequently found that some conducting moleculæ are interposed between the idio-electric moleculæ of bodies, in such manner that the effects are always a little complicated of those of bodies of both species.

401. We are now led to attempt an exposition of other researches of Coulomb, relative to an object very interesting to those who, having electrical experiments to make, are desirous to perform them with suitable precision. Physical experiments in general, that they may admit of comparison, should be referred to the point where all the circumstances are the same. If, for example, the temperature influences the results, such influence is made to disappear, either by maintaining a constant degree of heat or of cold, or by paying accurate regard to the variation: in like manner, when we employ one electric body successively to different results which we wish to compare with one another, the state of that body should be considered as permanent; and as this is never the case in reality, because the body always loses a certain quantity of its electricity in the interval between one operation and another, it is necessary to investigate means of estimating this loss, and to modify the results accordingly.

Now this loss arises from two causes: one is the contact of the surrounding air, which is always more or less charged with humid particles; the other is due to the idio-electric supports which sustain the electrified body, and of which the best chosen never insulate perfectly. Coulomb has been so successful as to discover the actions of those two causes, though exerted simultaneously, and to render experiments independent of their variations.

With respect to that which is occasioned by the air, he has found, by taking on one hand, the electric force lost by the body in a given time, such as 10 minutes, and on the other, the mean force resulting from the difference between the forces at the commencement and at the end of the experiment, divided by the number of minutes, that the ratio between those two forces is constant for the same rate of the air; which puts it in our power to compare together various results, from the mean forces answering to the different durations of the experiments.

402. It remained to consider the loss of electricity caused by supports. The experiments of Coulomb relative to this point have shewn, that when the electric density of the body is considerable, the diminution produced by the air and the supports together follows a much more rapid progress than that which is due to the contact of the air alone; but from the instant when the density becomes very weak, the influence of the support becomes nothing as to sense; so that when a body is employed whose electric density at the beginning of the experiment is moderate, we may content ourselves with paying attention to the loss occasioned by the contact of the air.

But this kind of resistance of the support to the transmission of the electric fluid can only be regarded as absolute during a certain time, which generally suffices for experiments. In reality, there is no support so idio-electric that its substance is not intermingled with conducting particles; and it is in consequence of the slowness with which the fluid leaps over the intervals between these latter moleculæ, that the electric density of the body resting upon the support experiences only insensible losses in a space of time more or less limited. Now, by giving more length to the support we augment the number of intervals which the fluid is obliged to run over before it arrives at the surrounding bodies: whence it follows that, when there is given the length of the support which insulates as completely as necessary a body whose density is likewise given, if we would employ another body charged more densely with a fluid, we may obtain an insulation as perfect as the former, by taking a proportionally longer support. Coulomb has found that, the state of the air being the same, the lengths of the supports should be as the square of the electric densities. Thus, for a second body whose electric density is double to that of the former, we must have a support four times longer than that which would insulate the first body.

Electric Attractions and Repulsions.

403. Electric attractions and repulsions form one of the subjects, on which philosophers have been much occupied, and which have greatly embarrassed those who have attempted to refer to the action of a single fluid two diametrically opposite effects, and that often succeed one another very rapidly in the same body. But if we here admit the combined actions of two fluids, the theory attains so happy a simplicity, that the sole enunciation of the hypothesis seems to be an abridged explication of the phenomena.

If we first suppose two bodies which were electrised, each by an additive portion of vitreous or resinous electricity, which had been transmitted to it, we may immediately see what ought to happen; since the principle that bodies animated with the same kind of electricity repel each another, while bodies solicited by different electricities attract each another, is only the literal translation, so to speak, of this other fundamental principle that the moleculæ of each of the constituent fluids act one upon another by repulsive forces, while they exert attractive forces upon the moleculæ of the other fluid.

404. This, however, requires some details, which will find their place in the account we are about to give of the means that may be employed to put the principle in practice. Let A, B, (fig. 37. Pl. VI.) be two balls of elder-pith or any other conducting matter, suspended by threads at a small distance from one another, and to which either electricity has been communicated. The fluids that envelope these balls will repel each other mutually; and their moleculæ would diffuse themselves into space by contrary motions, if the surrounding air did not confine them about each body. They can, therefore, only slide over the surfaces of the bodies, in such manner, for example, that the fluid of the body A being pushed back towards the posterior part *d*, will exert its effort upon the air itself bordering upon that point. The equilibrium being then broken between this air and that which is contiguous to the anterior part *c*, the latter will act by its elasticity upon the body A to impel it according to the direction *c h*; the same reasoning applies in a contrary sense to the body B, whence we may infer that the fluids and the bodies being carried away by a common motion ought to fly asunder.

405. Let us now conceive that one of the two bodies, A, for example, is solicited by vitreous electricity, while that of the body B is resinous. The fluids will then so attract one another that, in relation to the body A, which we shall continue to take for a term of comparison, the ebbing of the fluid shall be made towards the anterior part *c*: the fluid, accumulated in that

place, will act therefore by repulsion upon the neighbouring air: whence it follows that the air contiguous to the posterior part *d*, will impel the body according to the direction *dn*. The same effect will have place in a contrary direction with respect to the body B, and thus the fluids and the bodies are carried the one towards the other.

406. Now, that we may better comprehend the other cases in which there is a decomposition of the natural fluid of one or of both bodies, it is requisite first to consider the equilibrium of two bodies that are in their natural state. Let us denote these bodies by A and B, and limit ourselves to determining the manner in which A acts upon B, since all action is reciprocal. But the body A exerts upon the body B four different actions, arising from the repulsions of its two fluids against the homogeneous fluids of B, and from their attractions upon the fluids of a different nature, and it is easy to prove that the equilibrium depends upon the equality of these four actions.

Let us denote by V the vitreous fluid of A, and its resinous fluid by R; by *v* the vitreous fluid of B, and its resinous fluid by *r*. From what we have been saying it is manifest that, 1st. V attracts *r*; 2dly. R repels *r*; 3dly. R attracts *v*; 4thly. V repels *v*. Now, the two former forces are respectively equal; for if *r* were more or less attracted by N than repelled by R, it would move, which is contrary to the hypothesis of equilibrium. The two latter forces are also equal, for a similar reason, namely, that *v* is as much attracted by R as it is repelled by V.

Farther, the third force is equal to the first, that is, as much as V attracts *r*, so much R attracts *v*. For, on the one hand, the more attracted moleculæ *r* contains, or, which amounts to the same, the greater the mass of *r*, the more considerable is the effort with which it is carried towards V; on the other hand, the more attracting moleculæ V contains, the more velocity has each particle of r to move towards V: therefore, the quantity of motion which measures the total effort with which r is carried towards V, is represented by the product $r \times V$. If we substitute v for r, and R for V, we may prove by means of analogous reasoning, that the total effort with which v is carried towards R is expressed by the product $v \times R$.

But, the fluids being neutralised one by the other in each body, it results that the quantities of fluid V and v are proportional to the quantities R and r: or, in other words, we have $r \times V = v \times R$.

Now, since of the four forces we are here considering, three are equal respectively, and, that there may be an equilibrium, it is evident the fourth force must be equal to each of the three others; and it is in consequence of this equality between the four forces, that two bodies in the natural state have not any action upon one another.

407. This being premised, let us imagine a conducting body A of a spherical form, to be electrified in virtue of an additive quantity of vitreous fluid which it has received, and a second spherical body B, likewise a conductor, but in its natural state. The vitreous fluid that surrounds A will exercise a repulsive force upon the fluid of the same kind constituting part of the natural fluid of B, and an attractive force upon the resinous fluid, which is the other constituent principle of the same natural fluid. This latter fluid, therefore, will be decomposed in such manner that the particles of its resinous fluid will incline towards the part of B that is nearest to A, and those of the vitreous fluid will be driven towards the opposite part. These principles will at the same time issue out of the body B and diffuse themselves over its surface, in such manner that the fluid of resinous electricity will envelope the hemisphere turned towards A, and that of the vitreous electricity the hemisphere most remote from A.

Now, if we here apply the same reasoning to the additional fluid of A, as to that which makes part of its natural fluid, we shall conceive that at equal distances it would exert upon the two fluids of B actions which would mutually destroy one another. But, the distances in this case being not the same, the resinous fluid of B will be more attracted than the vitreous fluid; so that the two bodies, if they were freely suspended, would approach one towards another till they touched. Then, the additive quantity of the vitreous fluid of A uniting itself with the resinous fluid spread over the surface of B, there will result from that union a certain quantity of natural fluid which will enter into B; and it is very obvious that among the aggregate of fluids which would be found free at the moment of contact, there will remain a portion of vitreous fluid out of the state of combination. This portion will distribute itself between the two bodies, according to a certain law which we mentioned in par. (398); and both bodies being thus found in the state of vitreous electricity, will repel each other, as is shewn by experiment.

The same reasoning may be applied, by a simple change of names, to the case where the body A shall be charged by an additive quantity of resinous fluid.

408. It appears from hence that it is not exactly true, as the partisans of Franklin at first thought, that a body brought to a certain state of electricity attracts to it another body which is in its natural state. In this manner of conceiving the phenomenon, there is wanted an intermediate idea. The first body begins by making the other quit its natural state: it renders it attractable, and then attracts it.

409. It is now easy to conceive the effects of those metallic bells, which are struck alternately by a small globe likewise metallic, that serves for a clapper. Of the two neighbouring bells *g* and *n* (fig. 38.), one, as *g*, communicates with the conductor by means of its chain of suspension G *r*; the other bell *n* is suspended by a silken thread, and consequently is insulated with regard to the conductor, at the same time that it communicates with

the surrounding bodies through the intermedium of the chain *n h*. The metallic globe *d* also is suspended by a silk thread. At the moment when the conductor is charged, the fluid, which we shall suppose to be that of vitreous electricity, communicates itself to the bell *g*: and immediately, the globule *d*, attracted by that bell, proceeds till it strikes it, when it is directly repelled, for the reason before stated. It would tend, therefore, already, in consequence of this repulsion alone, to approach the bell *n*: but there is a farther solicitation on account of the electricity acquired, since the bell *n* is in the natural state: and lastly, the oscillatory motion favours still more the effect. But as soon as the globule is in contact with the bell *n*, it yields its fluid, which is lost by discharging itself along the chain *n h*. Then the globule which, in virtue of the oscillatory motion alone, will be approaching the bell *g*, will be so attracted to it by the action of the electric fluid diffused over the surface of the bell; so that the same causes recommencing their action, the same effects will be repeated, and so on successively.

410. If while the body A, of which we have spoken above (407), be still supposed a conductor, the body B be idio-electric, then the effects will be the same until contact, with this difference, that the two fluids of B will remain accumulated in the interior of that body, the one towards the part nearest to A, the other towards the opposite part. After the contact, the additional fluid of A not being able to penetrate the body B, to unite with that of a different kind which B contains, the attraction will subsist, and the two bodies will continue applied to one another. Thus, if you suspend a little globe of sealing wax by a silk thread from a conductor; at the moment when that conductor shall be electrised, the globe will approach it until contact, and will no more quit it.

411. We may devise other hypotheses, by supposing the states and the natures of the bodies A and B to vary, and shall obtain, upon each distinct supposition, results

analogous to the preceding. From the great variety of these results which might be exhibited, we shall select only one which will be useful as we proceed. Let us conceive that the two bodies A and B were idio-electric, and that the natural fluid of each had been decomposed in its interior. Suppose, moreover, these two bodies to be situated respectively with each other's sphere of activity, in such manner that the part of A which contains the vitreous fluid shall be turned towards that of B which contains the resinous fluid. If each of the two fluids of A acted at the same distance upon either of the fluids of B, there would be an equilibrium between their actions. But as the vitreous fluid acts at a smaller distance, its force will prevail, so that we may consider A as a body acting solely in virtue of a quantity v of vitreous fluid, proportional to the difference of the two actions. Hence it is easy to infer that the resinous fluid of B, being, in its turn, nearer to the point where the action of v is considered as residing, than the vitreous fluid of the same body B is, the attraction of v upon the former will be stronger than its repulsion against the latter; whence it follows that the two bodies will approach one another. If, on the contrary, the two parts, which the bodies turn towards each other, were animated by the same species of electricity, the bodies would fly farther asunder.

412. Electric attractions and repulsions are presented, in certain cases, under the appearance of an effect which would be due to the simultaneous action of two contrary causes; and they are phenomena of this kind especially, that have seduced the partisans of affluences and effluences. Place light bodies, such as little bits of sheet copper, upon a conductor which is at first in the natural state, and others beneath it at a small distance: at the moment when you electrify the conductor, the former will be repelled, while the latter will be attracted to be afterwards repelled in their turn. The first effect has been attributed to the effluent matter, and the second to the

affluent matter. Farther, it frequently happens that certain of these pieces, while they were attracted, recoil suddenly before they have arrived at contact: this was supposed to be because they then had reached the places where the two currents dashed against each other on meeting. But the true explication of these phenomena is presented, as of itself, from the principles we have established. The light bodies placed upon the conductor are repelled, because it communicates to them a portion of its fluid. Those which were situated beneath it experience for the most part an attraction which carries them on till the contact takes place, and to which a repulsion succeeds, because the part of them that is turned towards the conductor, which was at first solicited by an electricity contrary to its own, acquired one of the same nature as soon as they had arrived at contact: and as to the little bodies which started back from the conductor before they had touched it, their retrograde motion arises from this circumstance, that when the electricity is a little strong, there are always some jets of fluid which escape from the conductor through the surrounding air, and which incline in preference to such bodies as, on account of being terminated by points or angles, are most proper to draw down the electric fluid, as we shall see in the sequel; so that they undergo beforehand the effect which should only take place at contact.

413. We may here observe that the repulsion of bodies which have been regarded as electrised negatively, has always been the rock on which theorists have split. It was hard to conceive why those bodies of which each had lost a part of its fluid should be compelled to remove farther asunder, while a superabundance of fluid produced precisely the same effect. Most philosophers who have attempted to resolve this difficulty have had recourse to the action of the surrounding air, which they explained by different kinds of mechanism that we shall not stop to describe.

Nevertheless, they all suggested the notion that when, for example, we have electrised, on the one hand, two pieces of resin, and on the other, two vitreous bodies, by means of friction, the mutual repulsion of the former and that of the latter were effects in some sort parallel, the causes of which must be sought in the bodies themselves.

414. This leads us to a consideration which will complete our reasons for adopting the hypothesis in which the electric fluid is considered as composed of two different fluids. So long as philosophers confined themselves to employ in regard to electricity those methods which only approximated a little to the truth, and left to each individual the liberty of accommodating that which occurred in the phenomena to his own views of things, all might be satisfied with a single fluid alone. But, that we may judge properly of those methods we must refer to the time when the celebrated Æpinus undertook to reduce the theory to precision and verity, and to exhibit it in a state to sustain the test of the modern calculus. He commenced with the principle that the moleculæ of the electric fluid, which in this theory was considered as a simple being, repelled each other mutually, and might be attracted by all known bodies. Then, supposing two bodies A and B in the natural state, and consequently in electrical equilibrium, he first found that the real substance of the body A, for example, attracted the electric fluid of B, while the fluids of the two bodies mutually repelled each other, and he proved that the attraction was equal to the repulsion*. But farther, the electric fluid of A would attract, in its turn, the real matter of B, and this third action was also equal to each of the two former. Now, since there was an equilibrium, it was necessary to find somewhere a fourth force which should be

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* The reasoning which conducted him to this result was similar to that which we have employed (406) to demonstrate the equality of the actions exercised upon one another by the fluids of two bodies in the natural state.

attributed by Æpinus to the moleculæ of bodies. It is far less repugnant to a pure philosophy to admit a re-

for on this supposition Q augments; therefore, since in the natural state of bodies $Qm = Qq$; Qm and Qq augment equally, and consequently

$$Mq + Qm \text{ remains } = Qq + Mm, \text{ as before,}$$

or in other words, the sum of the attractions is still equal to that of the repulsions.

2dly. If the bodies A and B are both electrified positively, they ought to repel one another: for, when A is electrised positively, while B retains its natural fluid, we have

$$Mq + Qm = Qq + Mm, \text{ and } Qq > Mq.$$

But on the hypothesis before us where B is also electrised positively, q augments: therefore Qq augments in a greater ratio than Mq; and consequently

$$Mq + Qm < Qq + Mm;$$

that is, the sum of the repulsions prevails over that of the attractions.

3dly. If the body A be electrified positively, and B negatively, they ought to attract each other: for, when A is electrified positively, while B remains in its natural state, we have

$$Mq + mQ = Qq + Mm, \text{ and } Qq > Mq;$$

but since B is supposed negatively electrified, q diminishes; therefore Qq diminishes in a greater ratio than Mq, and hence

$$Mq + Qm > Qq + Mm;$$

that is, the sum of the attractions exceeds the sum of the repulsions.

4thly. When the body A is electrised negatively, B retaining its natural state, neither approaches to, nor recedes from the former: for, on this supposition Q diminishes; therefore, since in the natural state of both bodies $Qm = Qq$, Qm and Qq here decrease by the same quantity; consequently,

$$Mq + Qm = Qq + Mm;$$

or, the sum of the attractions equals that of the repulsions, and no motion ensues.

5thly. Two bodies A and B electrised negatively, ought to repel each other: for, A being electrised negatively while B remains in its natural state, we have

$$Mq + Qm = Qq + Mm, \text{ and } Qq < Mq;$$

but on the present supposition q diminishes: therefore Mq decreases in a greater ratio than Qq; of consequence,

$$Mq + Qm < Qq + Mm;$$

that is, the sum of the repulsions surpasses that of the attractions, and the bodies must fly farther asunder.

Thus much may suffice for a general view of Æpinus's theory. Those who wish to know more of it, are referred to the Hon. Mr. Cavendish's paper in vol. 61. of the *Philosophical Transactions*, which its author intended as an extension and more accurate application of the principles laid down by Æpinus.

pulsion at a distance between the moleculæ of two particular fluids, which, like all others, repel one another near contact, than between all the solid bodies in nature. Indeed, the philosophers who explained all by a single fluid had themselves begun to think, that its moleculæ repelled each other also, at a distance, from one surface to the other in the Leyden phial: and as what we denominate *action at a distance*, is, properly speaking, only a fact on which we may found or rest a theory, without investigating the cause that furnishes the point of support, it will suffice that the manner in which we conceive this fact may be adapted to our physics, and that all our hypotheses are connected together in our minds, in some such manner as the true causes whose results they enable us to represent, are connected in the matchless designs of Supreme Wisdom. Lastly, the hypothesis of two fluids is the only one, hitherto proposed, which possesses with regard to the two species of electricity, the advantage of establishing an exact parity between the actions that produce phenomena which observation presents us under marks of such strong resemblance, and of referring the whole to explications, either of which is nothing else, so to speak, than the counter-test of the other.

The Influence of Points.

415. The phenomenon now about to occupy our attention, and which has been denominated *the influence of points*, is among those exhibited by electricity, one of the most remarkable, both in itself and in the useful applications it has suggested for the preservation of

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For other explications of electric attractions and repulsions, the inquisitive reader may consult *Cavalla's Treatise on Electricity*, vol. I. pa. 109, &c., *Priestley's Hist. of Electricity*, pa. 253, and *Mem. of Roy. Irish Acad.* vol VII. pa. 139, &c. Tr.

edifices from the explosions of natural electricity. We shall confine ourselves to a brief description, and a concise sketch of the theory.

It must first be recollected that when an insulated body, which was previously in the natural state, is found moderately near another body charged with either kind of electricity, it becomes itself electric, and that in such manner that its part which is nearest to the second body is always solicited by the contrary electricity to that of such body. Changes in like manner occur in the state of a non-insulated conducting body, when it is within the sphere of activity of an electrified body. The action of the latter attracts into the anterior part of the non-insulated body the kind of electricity different from its own, and repels into the posterior part the electricity of the same nature. Now, the second body acting in its turn upon the first, it tends to attract its electricity, and this action is so strong in certain circumstances as to steal away the electricity from the first body, even at a very sensible distance: this happens when a fine metallic point is presented to a charged conductor; and it is singular to see a body, whose action would seem to be proportional to its minuteness, draw down so powerfully the electricity accumulated upon a considerable surface, and defeat almost entirely, in a moment, all the efforts of the philosopher to continue the charge of the conductor.

416. Franklin is the first who observed this power of points, (i), and he thought he had happily explained it, from the comparison between a point and a small force, which can execute in detail and by reiterated

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(i) Although Dr. Franklin first observed and evinced the whole effect of pointed bodies, both in drawing and throwing off electricity at greater distances than other bodies could do it; yet he frankly acknowledges that the power of points to throw off the electric matter was communicated to him by his friend Mr. Thomas Hopkinson. Tr.

actions, that of which a great force is incapable by a single action directed to the totality of the effect. But he afterwards suspected the accuracy of his explication, and he avowed his suspicion with that freedom and candour which is, with regard to true philosophers, another means of acquiring honour, in addition to that resulting from their discoveries*.

Without dwelling upon explications already refuted, even by the partisans of those who were their original authors, we shall attempt to reconcile the fact under contemplation with the theory we have adopted.

417. Observations evince that even a rounded body has a certain force to attract the fluid of an electrised conductor, since it will sometimes cause sparks to issue at the distance of more than a decimetre (nearly 4 inches). We have only, therefore, to shew that the force of a simple point is incomparably greater in producing the same effect.

Let us first imagine a single needle *a b* (fig. 39. pl. VI), whose point *a* is turned towards a conductor c which we shall suppose charged with vitreous electricity, at the same time that its extremity *b* communicates with the surrounding bodies. The action of the conductor will attract towards the point *a* the resinous fluid *r* which is disengaged from the natural fluid of the needle, and will repel towards the extremity *b* the vitreous fluid *v*. Let us now suppose a second needle *g d* to be placed at a small distance from the former, and

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* Exper. and Observ. on Electricity, pa. 144. et seq. We see by the elucidation which this celebrated philosopher himself gives of his idea, that it was suggested to him by the well-known anecdote of Sertorious, who, in order to convince his soldiers that perseverance was more efficacious than ardour and passion, gave orders to one man who was stout and vigorous, to pull out, all at once, the tail of an old and meagre horse; and to another man who was infirm and debilitated, to draw out, hair by hair, the tail of a young and robust horse. The latter accomplished, in time, the task assigned him : the efforts of the other answered no other end than to excite the laughter of the spectators. Ibid., pa. 152.

in a direction parallel to it, and let us conceive for a moment that the two needles have no action upon one another. The fluid v of the conductor will in like manner attract towards the point *g* a certain quantity of fluid *r*′ equal to *r*, and arising from the decomposition of the natural fluid of the needle, while it will repel towards the opposite part *d* another quantity of fluid *v*′ equal to *v*. Then, re-establishing the action of the two needles with regard to each other, the fluids *r* and *v*′ will, by reason of their mutual attraction, tend to move, the one from *a* towards *b*, the other from *d* towards *g*. So also, the reciprocal attraction of the fluids *r*′ and *v* will tend to bring, the one from *g* towards *d*, the other from *b* towards *a*. But these effects balance in part that of the conductor to attract towards the extremity of each needle the fluid of a nature contrary to its own.

The mutual action of the two needles will become still more sensible if they are brought nearer one to the other; because it will be exercised at a less distance, and according to less oblique directions.

Instead of two needles let us next suppose a very great number to be united in a bundle, to form, as it were, but one body. They will act, in like manner, upon each other to destroy in part the electric action from the conductor with respect to each of them; and that so much the more as their proximity will give them a great advantage relatively to the more remote position of the conductor, in consequence of the law of the inverse ratio of the squares of the distances, to which electric forces are subjected. Hence it results that the fluid of resinous electricity will be incomparably less condensed towards the extremity of the bundle of needles than it would be towards that of a single needle.

But, each needle reacts upon the conductor whose electricity it attracts; and that the force of the reaction may produce the effect observed it is sufficient if the equilibrium between the tendency of electricity to escape from the conductor, and the resistance of the air, be destroyed in a single point. The reaction in question will therefore be much more efficacious on the part of a single needle at whose extremity the resinous electricity is very much condensed, and all whose activity is directed towards one and the same point of the conductor, than on the part of a bundle of needles whose forces weaken one another, and are not sufficiently concentrated; and thus a single needle will become capable of exciting a rapid efflux of electric fluid that will abandon the conductor to precipitate itself upon the needle, which in its turn will transmit it to the surrounding bodies; after which it will immediately re-commence drawing down fresh fluid, if we continue to charge the conductor.

Now, a rounded body may be compared to a bundle of needles, which exercises only a feeble action to deprive the conductor of its electricity; while a body terminated by a point draws off that electricity very powerfully, by an action similar to that of the single needle of which we have been speaking.

418. It has been observed also that a conductor whereon a needle has been fixed, presents in some measure the inverse effect of the preceding. The electric fluid is, in this case, darted rapidly through the point of the needle in proportion as it arrives at the conductor. We may explain this effect in the same manner, by first supposing several needles attached to the conductor, and considering that the mutual repulsive forces of the portions of the fluids diffused through these needles, balances the action of the conductor to impel its own fluid towards their extremities. But we may substitute mentally, at any part whatever of a rounded conductor, a bundle of needles that act upon one another in the manner we have been de-

scribing. Now, when a single needle projects out beyond the others, which is similar to the case of a conductor terminated in a point, that isolated needle will be found freed from all the repulsive actions which would be exerted upon it by the other neighbouring needles, to hinder the conductor from repelling a part of its proper fluid towards the extremity of the same needle; and as this part of the fluid, which occupies only a very small surface, tends to condense itself there extremely, that it alone may maintain the equilibrium with all the rest of the fluid diffused about the conductor, its density will speedily become capable of overcoming the resistance of the air, and the fluid will escape at that point in proportion as it shall be furnished by the conductor.

419. When a sharp body is electrified according to either manner, there is produced at its extremity a light which may be perceived when the observer is placed in a due degree of obscurity. But this light varies in its aspect, according to the nature of the electricity acting upon the pointed body. Let us suppose that a body of this shape is fixed upon a conductor electrised vitreously: in that case the vitreous fluid will issue under the form of a beautiful luminous plume, whose rays will excite in the air a vibratory motion accompanied by a slight crackling noise. If, on the contrary, the conductor be resinously electrified, we shall see merely a luminous point at the extremity of the pointed body.

420. The same diversity of effects will take place, in the case where the pointed body, being in communication with the surrounding bodies, shall have its point turned towards an electrised conductor: the pointed body will give a plume, if the electricity be resinous, and a simple point of light, if it be vitreous. These effects may be obtained by presenting a metallic point alternately opposite to the hook, and to the exterior

furniture of a Leyden phial, charged to the usual degree, and suspended in the air by means of a silk cord: we shall see the luminous point and the plume succeed each other, becoming continually less and less perceptible, and at length disappearing at the moment when the phial, which in this case gradually discharged itself, shall have re-assumed its natural state.

This experiment suggests, as is manifest, a simple method of distinguishing the species of electricity with which a conductor is charged, by presenting to it a point at the distance of some centimetres (less than half inches). We shall return in the sequel to the circumstances which may thus modify the aspect of the light produced by the phenomena we have been speaking of.

421. When we bring near to an electrified conductor another body of a conducting nature, but of a rounded form, or terminated by a knob, the action of the latter, much weaker than in the case of a point, is limited at first to the attracting into the anterior part of the conductor a new quantity of fluid, which is kept there by the resistance of the air; this quantity augments, and at the same time the two parts of the bodies that are turned towards each other become more and more electrified in proportion as the distance between them diminishes; and there is a term where the air yielding to the attraction that solicits the two fluids, they escape with a kind of explosion, to unite with one another, and this explosion is accompanied by a vivid spark.

All who have seen electric experiments know, that a man placed upon an insulated stool and put in communication with the prime conductor of the machine, becomes in his turn capable of emitting sparks and of exhibiting various other phenomena, first observed by Dufay, who could scarcely recover from the surprise excited on perceiving that the power of producing them, already so singular in the machine, had been transferred to the experimenter himself.

It is known also that, when a person presents to this electrified man a spoonful of alcohol slightly heated, or of cold ether, the approach of his finger will give birth at once to light and inflammation (*k*).

422. One of the most interesting experiments in connection with the faculty possessed by the electric fluid of kindling different bodies, is that which is made by means of an instrument invented by the celebrated Volta, and bearing the name of the *Electric pistol.* It consists of a brass vessel in form of an oblong spheroid, which is pierced at its two vertices. Into one of these orifices there is introduced a glass tube of exactly the same diameter, which on one side projects about a centimetre (nearly 4 inches) beyond the vessel, and on the other, is prolonged inward nearly to the middle of the cavity of the vessel. This tube is traversed by a metallic stem, whose superior part, which projects beyond the tube, carries a ball of the same metal, and whose inferior part exceeds also the prolongation of the tube within. The other aperture, which is much larger, serves to introduce into the vessel a mixture of equal parts of inflammable gas and atmospheric air; after which that aperture is closed with a cork. The vessel is then taken into the hand by the middle of its convexity, and the metallic ball situated above the tube is presented to an electrised conductor, to extract a spark. The electric fluid being prevented by the tube from communicating with the vessel, passes along the stem which traverses that tube, and immediately the inflammable gas becomes enkindled, and issues with a smart explosion, driving before it the cork which is opposed to its passage.

(*k*) Many curious facts and observations relative to the luminous phenomena of electricity are given in *Nicholson's Journal*, Nos. 50, 63, and 60 N. S. Tr.

423. We have seen that neither the vitreous nor the resinous electric fluid, in its free state, has any affinity for different bodies, or is retained at their surface otherwise than by the resistance of the surrounding air. This observation suffices to indicate that if the air which surrounds an electrified conductor be suppressed, the fluid will be solicited by the mutual repulsive force of its moleculæ to diffuse itself in space; and experience shews that this kind of effusion is always accompanied by light. Having a long glass tube terminated at one end by a brass ferule, and at the other by a cock which you open to produce a vacuum in the tube, and then exactly close it again; you bring the ferule into contact with a conductor which is incessantly receiving fresh fluid by means of the electric machine, and at the same time you hold the tube by the cock: you will then observe a stream of a purple light to appear, which will fill the tube, and replenish itself continually. If you make use of the ferule as if to draw sparks from the conductor, the jet of light which, in this case, takes place by little intervals, will become much more brilliant. We have sought to diversify the phenomenon, by modifying in various ways the apparatus destined to produce it, and have caused the fluid to assume the form of a cascade, a sheaf, a sun, &c., thus multiplying, with respect to the eye, the beautiful effects of these experiments, worthy of occupying one of the first ranks among those which are to be exhibited publicly.

424. When the electric fluid has received a determination to escape from a body, and to traverse the surrounding air, it frequently happens that an odour is diffused analogous to that of garlick or of phosphorus. This odour becomes especially perceptible when we are near a luminous plume which is darted from a pointed body fixed upon the conductor of the machine.

The Leyden Experiment.

425. We are now arrived at the explication of one of the most important facts that has been discovered, relatively to electricity: which is that known under the name of the *Leyden experiment.* Some attribute this discovery to Cunæus, and others to Muschenbroek, who immediately imparted it to Reaumur (*l*). Never did

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(*l*) Dr Priestley affirms that this discovery was made by Von Kleist, dean of the cathedral in Camin, who, on the 4th of November 1745, sent an account of it to Dr. Lieberkuhn at Berlin: those, however, to whom Kleist's account was communicated did not succeed in performing his experiments. So that the discovery attained no celebrity until M. Cunæus of Leyden, happening to hold his glass vessel containing water in one hand, communicating with the prime conductor by means of a wire; and with the other hand disengaging it from the conductor, when he supposed the water had received as much electricity as the machine could give it, was surprised by a sudden and unexpected shock in his arms and breast. This experiment was repeated, and the first accounts of it published, in Holland, by M. M. Allamand and Muschenbroek; by Nollet, and Monnier in France; and by Gralath and Rugger, in Germany. Gralath contrived to increase the strength of the shock, by altering the shape and magnitude of the phial, as well as by charging several phials at the same time, forming thus what is now called the *electric battery*. Nollet was the first who tried the effect of the electric shock on brute animals, and he enlarged the circuit of its conveyance. Monnier is said to be the first who discovered that the Leyden phial would retain its electricity a considerable time after it was charged. Our countrymen Wilson, Canton, and Watson, added many important facts to those made known by experiments with the phial; some of them approaching nearly to the discovery of the different qualities of the electricity on the contrary sides of the glass, a discovery which was reserved for the ingenuity of Franklin; whose elucidation, rendered more precise by Æpinus and Cavendish, is now generally received. Mr. Cavendish also pointed out the exact degree of accumulation attainable by the phial, according to different laws of electric action.

The Leyden phial remained for some time in the state in which accident had presented it: the water contained in a vessel served for the interior, and the hand for the exterior furniture: but the dangers to which persons were exposed in experiments of this kind soon led to the substitution of the news of an extraordinary circumstance excite a more general sensation. There was scarcely a person who did not wish to electrify himself: it was the expression commonly adopted, and which has been perpetuated; as if the singularity of the experiment had caused it to be forgotten that there were many other ways of electrising a body. Such was the universal interest, that the philosophers were every where obliged to display the uses of electrical machines; and the multitude, for the first time, hasted to admire the wonders of philosophy, instead of the delusions of empirics.

Let us begin with shewing the ordinary method of performing the experiment. Suppose *a g* (fig. 40) to be a glass phial or jar, whose exterior surface is covered with a coating of tin foil to a certain height *c d*. The interior is filled up to the same altitude with small bits of sheet lead, or of sheet copper. In the explanation we shall give of the effects of the phial, we shall consider this interior matter, as occupying the place of a coating similar to that which is applied to the exterior surface. The phial has a cork stopper traversed by a metallic stem *a n*, whose lower part communicates with the bodies that constitute the interior furniture of the jar,

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another conducting body for the hand; some metal also was substituted for the interior water, because that liquid by oscillating moistened the inner surface, and established more or less the communication between the two surfaces.

These phials or jars are now made of various shapes and magnitudes: globular vessels with long narrow necks are best and most retentive; but as these are difficult to coat, thin cylindrical glass vessels are commonly used, in diameter about 4 inches, and in height 12 or 14: they are coated both within and on the outside, to about 2 or 2½ inches from the orifice, with tinfoil or some other substance electrifiable by communication. About 4 inches from each bottom within is a large cork, which receives a thick wire, ending in several ramifications, that touch the inside coating: the upper extremity of this wire which may be either straight or curved, is terminated by a metallic knob, considerably above the orifice of the jar. These vessels are sometimes girded by a metallic ring, to which chains or cords are attached, for their more convenient suspension. Tr.

and whose upper part, which is bent something like a shepherd's crook, is terminated by a metallic ball *b*. Take with one hand the phial by its bottom, and for a few moments place the ball *b* in contact with the conductor of an electrical machine in motion; then withdraw the phial from the conductor, and touch the ball *b* with a finger of the other hand, or with any metallic body held in that hand: immediately there will be felt a more or less violent shock in the two arms, especially at the joints, and sometimes even in the breast and other parts of the body.

Franklin imagined the cause of the phenomenon we have been describing to consist in the accumulation of the electric fluid upon the interior surface of the phial, while an equal portion of that upon its exterior surface was driven to the surrounding bodies by the repulsive power of the first fluid. It would hence result that the absolute quantity of electricity contained in the jar was the same as before, the exterior surface having lost as much fluid in the passage to the negative state, as the interior surface had received from the conductor in the passage to the positive state. The discharge therefore took place in consequence of a sudden restitution made, from the interior to the exterior surface, of all the fluid which the former had more than the latter, by means of the communication established between the two surfaces.

Æpinus added to this elucidation a new degree of precision; and the principles we shall adopt will be nearly the same as his, except that they are accommodated to the hypothesis of two fluids.

426. That we may obtain a more distinct and perspicuous notion of the manner in which the phial is charged, let us again contemplate the case where an uninsulated conducting body, in its natural state, approaches gradually towards the conductor of a common plate-machine, the plate being in motion (415).

In this case the natural fluid of the first body is decomposed, and the vitreous fluid resulting from that decomposition is repelled into the surrounding bodies, while the resinous fluid is attracted towards the extremity that is nearest the conductor of the machine. The quantity of this fluid augments as the distance between the two bodies diminishes; but its augmentation only takes place as far as a term but little distant, where the reciprocal attraction between that fluid and the vitreous fluid furnished by the machine, becomes capable of surmounting the resistance of the air, and causes those fluids to escape in order to be united. Let us now suppose that there is placed between the two bodies a plate of glass: this, being both solid and impermeable to the electric fluid, opposes as it were an invincible obstacle to the reunion of the vitreous and resinous fluids, which, in the preceding case, would soon open themselves a passage through the moveable particles of the air. Nothing, however, will hinder our bringing both the conductor of the machine and the uninsulated body into contact with the faces of the glass plate, and this proximity will give place to a much more abundant disengagement of the two fluids, which besides cannot become united; and if it be farther supposed that each face of the glass plate is coated with tinfoil, or a like sheeting of other metal, terminating at a certain distance from the edges, to prevent the communication from one surface to the other, each fluid will diffuse itself over the coating of its respective side; and this effect, due to the reciprocal attraction of the two fluids, will go on increasing till it reaches a certain limit which we shall presently determine.

Such, in general, is what occurs when we charge a Leyden phial. This instrument is, in fact, only an intermedium between two fluids, one vitreous supplied by the conductor, the other resinous furnished by the surrounding bodies, and whose developement, far more considerable than that which would obtain without such intermedium, prepares a much stronger explosion, when those fluids afterwards become suddenly reunited at the instant of the discharge.

427. Now, to enter a little more particularly into the explication of the phenomenon, let us conceive that A B (fig. 41) represents a segment of the glass plate that forms the curve surface of the phial coated in the usual way, *inpl* a portion of the metallic matter contiguous to the interior surface, and *oxst* a portion of the tinfoil that covers the exterior surface; that D is a conductor constituting part of an electrical machine, its extremity touching the metal *in*, and lastly that *ch* is a chain or any other conducting substance adhering by one extremity to the metal *ox*, while its opposite extremity communicates with the common reservoir.

Let us suppose that the conductor D acquires, by the operation of the machine, a certain quantity of vitreous fluid. As soon as that fluid begins to diffuse itself over the metal *in*, its action decomposes the natural fluid of the chain and of all the surrounding bodies to which that action extends; whence we may conclude, applying here the principles before laid down (426), that the surface *ox* must be charged with resinous fluid at the expense of the chain and the neighbouring bodies, while the vitreous fluid issuing from the combination is repelled in a direction contrary to the motion of the former.

Let *v′* be a particle of vitreous fluid which escapes along the chain: R the quantity of resinous fluid, which, at that instant, is spread over the surface *ox*; and V that of the vitreous fluid appertaining to the surface *in*. The particle *v′* at the same time that it yields to the repulsive force of the fluid V, is solicited by the attraction of the fluid R which tends to retain it; and since the repulsion of V prevails, at the same time that it acts from a greater distance upon the particle *v′*, we hence conclude that the quantity of vitreous fluid contained in V is greater than the quantity of resinous fluid in R; a more exact inference than in Franklin's theory (425), where it was supposed that the two surfaces were equally electrified, the one positively, the other negatively.

On the other hand, the moleculæ composing the fluid R tend to separate in consequence of their mutual repulsive force. But this force is balanced by the attraction of the moleculæ of the fluid V, which regain in point of number what they lose here also in regard to the distance. The latter moleculæ are, in like manner, solicited to separate farther, by their mutual repulsion; and this force cannot be entirely subdued by the attraction of the fluid R, whose fluid is less, and which acts more remotely than the repulsion in question. Hence, there will be a redundant portion of the fluid V, which will only be retained by the resistance of the surrounding air.

We may therefore imagine that the fluid V is composed of a portion U, which is retained at the surface *in* by the attraction of R, and of another portion *u*, whose moleculæ find no other obstacle to the effect of their mutual repulsion than that arising from the resistance of the air *.

If we continue to electrise the conductor D, the portion of fluid with which V is increased, will determine the decomposition of a new portion of natural fluid contained in the body communicating with *o x*: but at the same time the attraction of the fluid R, now become more abundant, will increase with regard to each new particle *v′* that tends to escape; which will render it necessary that the quantity *u* of vitreous fluid, em-

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* It is manifest that the quantity of fluid *u* will be always less than the quantity of fluid R, since the latter is less than that which is comprised in V or in U + *u*.

ployed to compensate the distance, should augment on its side; and there will be a term where the fluid *u* shall have no more than the force requisite to balance the resistance of the air. Beyond this limit, if the electrisation be pursued, all the fresh moleculæ of fluid which the conductor D shall furnish, will escape in succession; in other words, the glass plate will be found to have reached its point of saturation: for it is obvious enough that there will then be no longer any thing disengaged from the bodies in communication with *o x*; because, as much as the force of V would act to repel, for example, a particle of vitreous fluid that might issue from the combination, so much would the attraction of R tend to retain it.

Things being in this state, you detach the chain *c h*, and apply a finger to the surface *o x*. Nothing new will happen on account of this contact: for you have only substituted your finger for the chain, all whose parts were solicited, as we have remarked, by forces which were in equilibrio. Then, remove the same finger to the surface *i n*: in that case, the equilibrium will no longer obtain, since nothing balances the action of the portion of fluid *u*, which is merely retained by the resistance of the air. That redundant portion will therefore act upon the natural fluid of the finger, to decompose it; hence it will repel the vitreous fluid of that finger towards the lower parts, and unite itself with the resinous fluid, to recompose the natural fluid lost in the surrounding bodies.

As to the fluid U, it will continue to be kept upon the surface *in*, by the attraction of the fluid R, and the equilibrium will be re-established between the electric forces referred to the different points of that surface. But it will be broken at the surface *o x*, because the portion of resinous electricity retained there by the attraction of the fluid *u*, which the finger has taken up, will be no more than by the adjacent air. If, therefore, you bring back the finger towards the surface *o x*, there will be made a new decomposition of the fluid of that finger in a contrary sense; such that the vitreous part of the same fluid shall unite with that of the fluid R, which was in excess.

It is now easy to conceive that by applying successively the finger to the two faces, by which the equilibrium between the electric forces will be alternately disturbed in like manner, you by degrees accomplish the complete discharge of the phial; that is, each of the two faces will be deprived of its excess of vitreous and resinous electricity, after which it will be found reduced to its natural state. In such cases, it is observed that the re-establishment of the equilibrium becomes sensible, each time, by a little spark which darts out between the finger and the surface touched.

But if, instead of thus discharging the glass plate by reiterated operations, you apply both hands at the same time to the two opposite faces of that plate, all the effects which would succeed one another in the former manner of operating, will here concur together; so that the two faces will attract the fluids of different kinds, which constitute part of the natural fluid of the two arms, to combine with those fluids, and repel with the same velocity the heterogeneous fluids of the one towards the other: and it is to this complication of effects, which take place with great energy and in a manner instantaneously as to sense, that must be ascribed, in general, the strong shock sustained by those who make the experiment of the Leyden phial. This is a result of mechanics, if we limit the consideration to the forces on which the phenomenon depends: it is a double operation of analysis and synthesis, if we conceive those forces as existing in the agents suggested by a plausible theory.

428. When a glass plate is discharged by repeated contacts in the way we have just been describing, the quantities of vitreous or resinous fluid taken up successively

from each surface *i n* or *o x*, must necessarily diminish from one contact to the other. Biot having investigated, by the calculus, the law of that diminution, was led to this interesting result that the quantities of fluid in question form a geometrical progression *.

429. What rendered the Leyden experiment still more curious was that it might be made upon a large society; so that many hundreds of persons arranged in a semi-

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* The following demonstration of this result its celebrated author was pleased to communicate to us. Let A (fig. 42. pl. VIII) be the surface of the glass plate which communicated with the conductor, B that which communicated with the earth; let us denote by E the quantity of vitreous fluid which was accumulated upon A at the moment when the plate is insulated, and by e the quantity of resinous fluid which was fixed upon B. There will be between E and e a certain relation depending upon the thickness of the plate; this ratio will be constant for the same plate, since if E conceals e, k E will conceal $k\,e$ at the same distance. We shall therefore have between e and E the equation $e + m\,E = o$, m being a positive constant quantity less than unity.

At the moment when A is touched a part of the fluid which was there accumulated will run off into the earth, and there will only remain the quantity that e can conceal at the same distance. Let E' be that quantity; then we shall have the same relation between E' and e, as between e and E, which will give $E' + m\,e = o$. The tension will then be on the side of the electricity e. If B be afterwards touched, there will remain a certain quantity of electricity which we shall call e; the tension will arise again on the other face, and we shall have $e' + m\,E' = o$.

By continuing to represent the effects of the different contacts, we shall find a series of equations similar to the preceding; and, by combining them together, shall have,

$$e + m\,E = o,$$
$$E' + m\,e = o,$$
$$e' + m\,E' = o,$$
$$E'' + m\,E' = o,$$
$$e^n + m\,E^n = o,$$
$$E^{n+1} + m\,e^n = o,$$ n being the number of contacts. Hence we deduce the two following systems of equations, each of which relates to one of the faces of the glass plate:

$E' = m^2 E$. $\qquad e' = m^2 e$.

$E'' = m^2 E'$. $\qquad e'' = m^2 e'$.

$E^{n+1} = m^2 E\,n$. $\qquad e^{n+1} = m^2 e\,n$.

The first system shews the quantities of fluid successively remainin upon the face A, and the second those which remain upon the face B.

circle were all struck at the same instant. Indeed it was soon resolved to extend still more the field of the experiment, by causing to enter into the communication, independent of the numerous observers, the water of a river, long iron wires, and even portions of the earth. The French began this extension, and caused the commotion to run over a space of two thousand toises, through which it was transmitted in a very sensible manner. The English went beyond even this result, and in one of their

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From these formulæ we may calculate the quantities in question in functions of E and e, and shall have

$$E' = m^2 E. \qquad e' = m^2 e.$$
$$E'' m = m^4 E. \qquad e'' = m^4 e.$$
$$E^{n+1} = m^{2(n+1)} E. \qquad e^{n+1} = m^{2(n+1)} e.$$

The above obviously form geometrical progressions. Their differences will give the losses of fluid sustained successively by the two faces, in virtue of the repeated contacts: they will be expressed by

$$E - E' = (1 - m^2) E. \qquad e - e' = (1 - m_2) e.$$
$$E' - E'' = (1 - m^2) m^2 E. \qquad e' - e'' = (1 - m^2) m^2 e.$$
$$E^n - E^{n+1} = (1 - m^2) m^{2n} E. \qquad e^n - e^{n+1} = (1 - m_2) m^{2n} e.$$

And it will be evident from a simple inspection of these formulæ, that the losses of fluid which obtain relatively to each face, in proportion as the plate is discharged, follow in like manner a decreasing geometrical progression (270). Hence, the smaller the quantity m is, the more rapidly will the quantities remaining of the fluid, and their corresponding losses, decrease; so that after a small number of contacts they will become insensible, and the plate will appear entirely discharged. As the value of m depends upon the thickness of the glass, it is clear that a very thin glass will require more time to discharge it in this manner, than one that is thicker.

Strictly speaking, it would require an infinite series of contacts to discharge the glass plate entirely: for, if we add together the formulæ which exhibit the successive losses, and suppose them continued to infinity, we shall find for their sum, $(1 - m^2) E (1 + m^2 + m^4 + m^6 + \&c.)$. Now the series comprised between the last parenthesis has for its sum $\frac{1}{1 - m_2}$; whence it results that the aggregate of the losses relative to the face A is E. And in like manner we shall find that the sum of the losses of the face B is represented by e. This, however, is a case purely mathematical; and it generally happens that after a certain number of contacts, the quantity of electricity remaining ceases to be perceptible.

experiments the journey (for it is one) of the electric property was four English miles. They attempted to measure the velocity of the commotion, by a method analogous to that which has been employed to measure that of sound (350): but the difference between the moment of departure and that of the return appeared to them inappreciable.

430. If we would actually make use of a phial to verify and render perceptible the explication which we have given of its effects (427), on the supposition that it was discharged progressively by contacts repeated at the two surfaces; we should first electrify it in the manner described, then cause to pass under the hook *m* (fig. 40. pl. VI.) a silk cord by means of which we could hold it suspended, or we would place it upon an insulator, after which we would touch alternately, with a finger, the ball *b* and the exterior coating.

431. If the phial were insulated while the ball *b* was in contact with the conductor of the machine, it would not become changed, especially in the case when the surrounding air was very dry. Yet its interior surface would receive from the conductor a small quantity of fluid; whose repulsion being without effect upon the fluid of the same name, situated in the exterior coating, could not cause the latter to pass to the opposite state; a circumstance necessary in determining the charge of the phial.

432. The thinner the phial, cæteris paribus, the more powerfully it may be electrised. For, on one hand, the vitreous fluid of *i l p n* (fig. 41) acts with more energy upon that of the opposite part, because of a less distance between the two surfaces: on the other hand, the resinous fluid in the free state upon the plate *o t s x*, being more abundant, becomes capable of maintaining by its attraction a greater quantity of vitreous fluid in the plate *i l p n:* whence it follows, that the point of saturation of the phial will be more elevated than if the glass had more thickness. In this case, the two quantities of fluid v and

it will differ less one from another, or, which amounts to the same, the quantity *u* which compensates what the force of the fluid *i l p n* loses in regard to the distance, will be smaller, since the distance itself is found diminished; in such manner that this quantity will become evanescent when the thickness of the glass is supposed infinitely small.

433. As the glass is never perfectly impermeable to the electric fluid, there is always a certain portion of vitreous or of resinous fluid which penetrates a little into the thickness of the phial, where it is, if we may so speak, rammed in, during the process of electrisation. At the moment of the discharge this portion of fluid remains engaged in the glass, in consequence of the coercive force, so that it communicates nothing to the effect then produced. But afterwards its moleculæ become disengaged from one another, and pass into the coating, where they cause a new disposition to give the shock, though in a much weaker degree than the first time. This is often remarked by those who have made the Leyden experiment, and think the phial entirely discharged; but taking it again after a short interval, and applying anew the finger to the ball which terminates the hook, they are surprised at receiving a fresh shock: this may occur at several distant trials, but by degrees always diminishing.

434. When we would discharge the phial without any commotion, we use a brass bar *e f h* (fig. 44. pl. VII), bent into an arch and terminated by two balls; this has received the name of *exciter*. We take hold of it near the part *f* of its curvature, place the ball *h* upon some point of the exterior coating of the phial, and then approach the ball *e* to that which terminates the hook; thus producing with impunity the discharge, accompanied by a strong spark. By a similar method we may enkindle cotton. To accomplish this, cover the ball *b* (fig. 40. pl. VI.) with a thin film of that substance, and then sprinkle it over with pounded resin; at the moment of the dis-

charge the spark will occasion the inflammation of the cotton.

Sometimes there is substituted for the phial a pane or square of glass, coated on each face with tinfoil, which does not extend to the edges of the glass, but leaves all round a space of about 54 millimetres, or 2 inches, uncovered. The square is laid flat upon a table, and there is interposed between the table and the inferior coating a small chain whose lower end reaches to the ground. By means of a metallic stem a communication is established between the superior coating and the conductor of the machine. At the moment when the apparatus is strongly electrised, if the operator take in one hand the chain in contact with the inferior coating, and touch the superior coating with the other hand, he will receive a violent shock. But it is easy to avoid the shock, by using an exciter to discharge the apparatus. The square of glass under consideration has received the names of the *magic pane*, and the *fulminating square.*

435. Several jars may be charged at once by disposing them in the following manner. Suspend from the conductor of the machine a first jar under which is fixed a hook: make use of this hook to suspend a second jar from the first: continue the series by similar means, and suspend from the hook fixed under the last jar a chain which communicates with the ground. Afterwards when the plate of the machine is put in motion, the vitreous fluid which accumulates upon the interior coating of the first jar will decompose the natural fluid of the exterior coating, and repel the vitreous part of that fluid to the interior coating of the second jar; and so on successively. Hence it results that all the surfaces are charged, one by the intervention of the other; except the first, which receives its charge from the conductor, and the last, which receives its from the surrounding bodies. If we detach the chain suspended under the last jar, we may discharge them all by repetitions, as we have explained in the case of

a single phial (427), confining ourselves to touching alternately first the knob which communicates with the interior furniture of the highest jar, then the exterior coating of the lowest *. We may also discharge the whole of the jars at once, by receiving the shock, on the simultaneous contact of both hands applied to the same places. This method of charging several jars suspended one from another, is called the *charge by cascade*.

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* Biot has extended to the case we are now considering, the analysis which enabled him to determine the law regulating the losses of fluid sustained by the two surfaces of the same phial, by successive contacts. In developing this new result he confined himself to the contemplation of the states of three glass plates (fig. 43. pl. VII.) which communicate respectively, and which represent three jars disposed as we have described. These plates being considered as equal in all respects, we shall first have,

$$e + mE = 0.$$
$$e_1 + mE_1 = 0.$$
$$e_2 + mE_2 = 0.$$

But here there are particular conditions; namely, that e and E_1, result from the decomposition of the natural fluid of the face B, and that in like manner e_1 and E_2 result from the decomposition of natural fluid in the face B′. Hence arise two new equations to unite with the preceding; which are

$$e + E_1 = 0.$$
$$e_1 + E_2 = 0.$$

If while B″ is insulated, the face A be touched, all the quantities of fluid will vary, except e_2; whence, making use of the same letters, we shall have

$$E' + me' = 0. \qquad e' + E'_1 = 0.$$
$$E'_1 + me'_1 = 0. \qquad e'_1 + E'_2 = 0.$$
$$E'_2 + me'_2 = 0.$$

And so on for each contact.

The formulæ relative to the first state of equilibrium give, by elimination,

$$e + mE = 0. \qquad E_1 - mE = 0.$$
$$e_1 + m^2E = 0. \qquad E_2 - m^2E = 0.$$
$$e_2 + m^3E = 0.$$

So that the quantities of concealed fluid upon each of the faces B, B′, B″, conform to a decreasing geometrical progression. It will be the same

436. From the observation that the effect of the discharge takes place with more energy, in proportion as the extent of the surfaces are augmented on which the two fluids accumulate, those powerful *batteries* have been contrived which result from an assemblage of many jars that are made to act all at once. By means of this apparatus, an iron wire which is considered to make part of the exciter, becomes incandescent, and is dispersed in an infinite number of grains which are in the state of an oxyde. Place some leaf gold between two glasses which are strongly pressed one against the other, by means of a little wooden press; one of the extremities of the leaf communicating with the exterior coating of the apparatus, and the other with one of the balls of the exciter. A bird, placed in such a manner as to receive the shock, is struck dead. The spectator, startled at the violent explosion thus produced, is less surprised when he hears it said that the matter of electricity is the same as that of lightning (*m*).

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whatever be the number of plates in communication, and the last will be much less charged than the first. This difference will be so much the greater, as *m* is less, and of consequence it will increase in proportion as the plates shall be thicker.

By combining the formulæ that relate to the first contact we shall have

$$E' + m^3 e_2 = o.$$
$$E'_1 + m^2 e_1 = o.$$
$$E'_2 + m e_2 = o.$$

And putting for *e* its value, there results,

$$E' - m^6 E = o.$$
$$E'_1 - m^5 E = o.$$
$$E'_2 - m^4 E = o.$$

Therefore, the quantity E', of fluid that remains upon the face A, after the first contact, is also much less than if there had been only a single plate.

(*m*) There is nothing so formidable amongst an electric apparatus as the electric battery, which, as it is commonly constructed, differs from what M. Haüy has described above: it consists of a number of Leyden jars connected together in a box. The bottom of the box is covered with tinfoil: a hook projects on the outside of the box, by which any substance

437. With regard to the effects which obtain when a strong shock is exerted upon a very thin plate of metal, as in the experiment we have been citing, it would seem that their true cause is the expansive force of the electric fluid which acts to dilate the bodies, and separate their particles one from another. If the metal is not oxydable immediately, the action of this expansive force is limited to the dispersion of the moleculæ. The elevation of temperature which appears unexpectedly in this case, is pro-

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may be connected with the outside of the jars; their insides are all connected by wire or some metallic communication. By means of this, a great number of very surprising and interesting experiments may be performed: and though, when very large, it ought always to be used with caution, yet it cannot be said that the apparatus of an electrician is complete without it. Its effects in rending various bodies, in firing gunpowder, in melting wires, and in imitating all the effects of lightning, are highly curious and worthy of notice.

A most compendious battery may be made according to the following directions of Professor Robison. "Choose some very flat and thin panes of the best crown glass, coat a circle *a b c d* (fig. T. pl. VII.) in the middle of both surfaces, so as to leave a sufficient border uncoated for preventing a spontaneous discharge; let each of them have a narrow slip of tinfoil *a* reaching from the coating to the edge on one side, and a similar slip *c* leading to the opposite edge on the other side. Lay them on each other, so that the slips of two adjoining plates may coincide. Connect all the ends of these slips on one side together by a slip of the same foil, or a wire which touches them all. Then, connecting one of these collecting slips with the prime conductor, and the other with the ground, we may charge and discharge the whole together. If the panes be round, or exact squares, we may employ as few of them together as we please, by setting the whole in an open frame, like an old-fashioned plate-warmer; and then turning the set which we would employ together at right angles to the rest. This evidently detaches the two parcels from each other. This battery may be varied in many ways; and if the whole is always to be employed together, we may make it extremely retentive, by covering the uncoated border of the plate with melted pitch, and, while it is soft, pressing down its neighbour on it till the metallic coatings touch."

On the same principle, another compendious battery may be made by alternate layers of tinfoil and hard varnish, or by coating plates of very clear and dry Muscovy glass. But these must be used with caution, lest they be burst by a spontaneous discharge: in which case we cannot discover where the flaw has happened. They make a surprising accumulation, without shewing any vivid electricity. Tr.

bably occasioned by the circumstance that the parts which are most dilated compress those which are dilated less; whence results a kind of condensation occasioning a disengagement of heat (148). Bertholet and Charles, having caused powerful electric discharges to traverse a wire of platina, observed that such wire had merely acquired a degree of heat which they estimated to be nearly equal to that of boiling water, and which was, consequently, far inferior to the heat capable of producing the fusion of the platina. If the metal is susceptible of an easy oxydation; if, for example, it be a wire of iron or of copper, the separation of the moleculæ, by diminishing their reciprocal affinity, disposes them to combine with the oxygen of the surrounding air; and it is then the oxydation itself that produces the high degree of heat to which the metal is found exposed *.

438. Among the different results that have been obtained by the aid of a violent electric explosion, there is one which has furnished to the partisans of Franklin's doctrine a specious objection to the hypothesis of two fluids: we will shew in what it consists. Let *a m b*, *c n d*, (fig. 45. pl. VII.) be two metallic conductors, one of which, as *a m b*, communicates with the interior surface of a battery, and the other, *c n d*, with its exterior surface. Suppose that there is placed between these two conductors a card, whose vertical projection is represented by G H, in such manner that the conductor *a m b* shall touch this card below, while the conductor *c n d* touches it above. If the battery be electrised in the usual way there will be a term where the two fluids will be found so accumulated in the conductors, that their mutual attraction will give place to a spontaneous discharge of the battery. In this case the spark, commencing at the extremity *m* of the conductor which is in the vitreous state, will glide over the surface *m t* of the card, where it will

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* Statique Chimique, t. I, p. 209 and 263.

form a train of light; at the same instant the card is pierced in *t*, and a luminous point is perceived at the extremity *n* of the conductor *c n d*. This experiment accords very well with the supposition of a single fluid which, after being accumulated upon the interior surface of the battery, abandons it at the moment of the explosion, and, precipitating itself upon the conductor *c n d*, goes to replace the fluid of which the exterior surface was deprived.

They adduce, also, in favour of the same opinion the diversity of aspects under which the light was presented which may be perceived at the extremity of a pointed body situated near an electrified conductor. When the plume appeared, the electric fluid issued from the pointed body to yield itself to the conductor which was in the negative state; and when on the contrary, only a luminous point was seen, the fluid would escape from the conductor electrified positively, and move towards the point which, being in the opposite state, would attract the fluid. Tremery, engineer of mines, a philosopher of distinguished merit, has, with a view of resolving these difficulties, devised a very admissible hypothesis, which he has confirmed by ingenious experiments [*]. According to his hypothesis, the coercive force of idio-electric bodies, that is to say, the resistance they opposed to the motion of the electric fluid in their interior (400), could not be the same for both the vitreous and resinous fluids, so that it might easily happen that, in certain bodies, it should be incomparably greater with respect to one of the fluids than to the other. Atmospheric air might be in this latter case, and might oppose a very great resistance to the motion of the resinous fluid, while it would not resist with near the same force the motion of the vitreous fluid.

According to this hypothesis, when the apparatus we have been describing was employed, it would happen that

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[*] Journal de Phys.; Floreal an. 10, p. 357 et seq.

at the moment of the discharge the vitreous fluid would issue from the conductor *a m b*, and go on to unite itself to the resinous fluid which might be kept about the conductor *c n d* by the coercive force of the air; and its passage through the card should take place at the point *t* situated immediately beneath the point *n*: and this, as we have seen, is conformable to the experiment.

Now, if by the effect of any cause whatever, such as one that should produce a change in the density of the air, the coercive force of this air for the resinous fluid might be diminished relatively to that which would obtain for the vitreous fluid, in such manner that the two forces might arrive at equality; then the two fluids would at the moment of the discharge move one towards another, so that a luminous plume would be perceived at the point of each conductor.

Other suppositions may be made, conformably to which the coercive force for the vitreous fluid would in its turn predominate over that which should take place with regard to the resinous fluid; and if the former should become incomparably greater than the other, the inverse phenomenon of that which is observed in the ordinary case would be exhibited.

To verify this theory Tremery placed the apparatus represented in fig. 45, under the receiver of an air-pump, and exhausted it to the point where the pressure of the air, indicated by a barometer gage, was no more than 14 centimetres, or about 5 inches and 2 lines French. The apparatus being afterwards electrified, the explosion was made in such manner that the card was pierced at the point *s*, situated nearly in the middle of the distance between the extremities *m*, *n*, of the two conductors. This very remarkable phenomenon indicated that, in consequence of the diminution the density of the air had undergone, the relation between its coercive forces, with respect to the two fluids, had so varied that they were become perceptibly equal.

The same philosopher next permitted the air to re-enter the receiver, at different operations, by small portions; and he observed that every new degree of density produced a particular situation of the place where the card was pierced, such position being always between the middle *s* of the card, and the extremity *n* of the resinously electrised conductor.

We may now see what occasions the difference between the two aspects under which the light presents itself that we perceive at the extremity of a pointed body, according to the diversity of circumstances. If the pointed body be situated opposite a conductor charged with resinous fluid, the vitreous fluid of the former will be thrown off under the form of diverging rays, to proceed towards the conductor where the resinous fluid which exerts its attraction upon it is kept by the coercive force of the air. When, on the contrary, the conductor is electrised vitreously, its fluid will be attracted by the pointed body, and the re-union of that fluid with the resinous fluid, which only takes place at the extremity of the same body, will produce the luminous point perceived in that place.

Description of some Particular Electrical Instruments.

439. Philosophers have invented many kinds of instruments suited to various experiments, each of which has an especial object. Four of these instruments appear to us to merit particular explication. The first is the *Electrophorus*, so called, because it retains its electric virtue a long time. It is composed of a foot-plate or cake *st* (fig. 46) of resinous matter, upon which is placed a metallic disc *ag*, attached by its middle to a glass cylinder *mn*. This disc being first separated from the resin, the latter is

electrified by striking it with the skin of a hare or a rabbit, or other hairy animal; the metallic disc is then applied upon the resin, and a finger is laid upon the same resin for a short interval. This done, the finger is withdrawn, and the disc is lifted up by means of the glass cylinder *m n*, intended to maintain the insulation. If we then present the finger, or an exciter, to the disc, we shall see a spark appear between them. By replacing the disc upon the resin, without being obliged to electrise it afresh, and repeating the rest of the same process, we shall obtain new sparks whose force will not appear perceptibly diminished; and if we make use of the hook of a Leyden phial to produce those sparks, it will soon become charged.

To explain these effects it must be remarked that, at the moment when the metallic disc is placed upon the foot-cake *s t* which has been electrified, the resinous fluid of that cake attracts to it the vitreous fluid of the metallic disc, which, since it cannot pass into the resin whose nature is idio-electric, remains upon the inferior surface of the disc. The resinous fluid of the latter is at the same time repelled towards the superior surface. But the disc, having here only its natural quantity of electric fluid, which alone is decomposed, its resinous fluid acts more powerfully upon the finger in contact with the disc, than the vitreous fluid which is at a greater distance (407). Now this action is farther aided by that of the fluid of the same name which appertains to the resin; and hence the vitreous fluid constituting part of the natural fluid contained in the finger will be attracted by the metallic disc, and will unite with the resinous fluid diffused over the upper surface. If, therefore, after having withdrawn the finger, the metallic disc be elevated, it will be found in the state of vitreous electricity; after which it is easy to comprehend all the rest.

Commonly the cake of resinous matter has for its support, (or, as it is usually called, its *sole*) another metallic disc upon which the resin was poured when it was in a state of fusion. The fluid that occupies the upper surface of the cake acts also through its thickness upon the disc which adheres to its lower surface. But we here pay no regard to this action, because it is very weak; and consider only the former, which alone is directed towards the effect proposed to be obtained.

440. For the invention of the second instrument, called the *Condenser*, we are indebted to the celebrated Volta. Its use is to render sensible the very small quantities of electricity furnished by the surrounding bodies, by exciting them to accumulate upon the surface which it presents to their action. This instrument only differs from the electrophorus in so far that for the cake of resin there is substituted a body of that class which only insulates imperfectly, and which holds the middle rank between conductors and idio-electrics: such, for example, is white marble. Let us conceive that the disc, being placed upon a piece of that substance, receives by communication a weak degree of electricity which we shall suppose to be resinous. The fluid of this electricity will decompose a little the natural fluid of the white marble, repelling the resinous fluid downwards, and attracting the vitreous fluid upwards. The marble in its turn will act upon the disc, in virtue of its vitreous electricity, whose force is exerted nearer, to retain there the small portion of resinous electricity communicated. A second quantity of fluid arriving at the metallic disc will decompose a new portion of natural fluid included in the marble, which on its side will acquire a fresh degree of attractive force, and so on successively. This, then, is what the marble performs: it allows a certain play to the fluid which it contains, to move there, since it is a semi-conductor; but as it is also in part idio-electric, the resinous fluid of the disc which it attracts is arrested by the resistance it experiences at the place of contact, a resistance which is made by plane sur-

faces whose figure is less accessory to the effect of attraction than that of curvilinear surfaces. The small quantities of electricity received successively by the disc will therefore continue to accumulate there to the term when, after having lifted it up, if we present a finger to it, we may draw off a more or less vivid spark (*n*).

441. The third instrument is the *Electrometer* of Cavallo. It consists of two balls of elder-pith of a very small diameter, suspended by means of two hairs from a brass ball which rests upon the orifice of a kind of glass flask. A stick of sealing-wax electrified by friction is presented at a small distance from the ball, while a finger is applied upon that ball. Afterwards, the operator withdraws, first the finger, then the wax; and it is easy to conceive, by a reasoning similar to that which we adopted relative to the electrophorus (439), that, all the apparatus being then charged with vitreous electricity, ought to be repelled and to be kept separated from one another. Every time the wax is presented afresh at a certain distance from the point of suspension, the balls will mutually approach, because the wax brings back into the brass ball a part of the electricity from the pith ones. If the distance be diminished it may happen that the balls, by losing all their additional fluid, will re-enter their natural state, and thus come to touch each other: then if you bring the stick of sealing-wax still nearer, the force of its resinous electricity, by causing a greater quantity of vitreous fluid to incline towards the point of suspension, will decompose the natural fluid of the balls, which shall hence pass to the state of resinous electricity, and repel one another again: so

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(*n*) Volta invented three condensers, of which that above described was the first in the order of time. It is certainly an ingenious instrument; though we think neither its author nor any other person whose writings we have seen, has explained its operations by a very satisfactory theory. Mr. Cavallo has improved this condenser, by connecting the moveable plate, after removal, with a smaller condenser. Tr.

that, to the eyes of those to whom this observation first occurred, without a clear insight into the theory, it appeared to contradict the former, where the wax, by approaching the point of suspension, solicited the balls to move one towards the other.

442. This electrometer furnishes an easy method of determining the species of electricity of any body whatever. For example, in the case we have been relating, all bodies which shall have the electricity vitreous will, if brought near the ball that terminates the apparatus, augment the separation between the two little balls of elder-pith; if, on the contrary, the body be charged with resinous electricity, the first motion of the balls will be one of approach towards each other.

If there be attached to the metallic ball a needle terminated by a fine point, and the apparatus be exposed at a window, during the time of a storm, the balls will be seen frequently to start spontaneously asunder; and, on electrifying them by the process we have just pointed out, we may ascertain the species of electricity with which the air is animated (*o*).

(*o*) Besides the above, a great variety of electrometers have been contrived by different philosophers, to describe only a few of the most ingenious of which would lead us far beyond the limits of a note: we must therefore satisfy ourselves with referring the reader to other performances for farther information on this point.

Mr. Cavallo has invented not merely one, but several electrometers for different purposes, descriptions of which may be seen in his *Treatise on Electricity*, pa. 370, &c. Bennet's electrometer, which is a very delicate one in its use and application, is described at pa. 345. vol. ii. of *Nicholson's Natural Philosophy*. A very valuable electrometer is described in No. 85. art. Electricity, *Sup. Ency. Britan:* and an improved discharging electrometer, by A. W. Von Hauch, in the *Philosophical Magazine*, vol. iv. pa. 267. Coulomb's accurate electrometer, which is adapted to ascertain the smallest quantities of electricity, is already described in par. 393, of this Treatise. For the measure of electric repulsions, it is undoubtedly superior to any instrument that has yet been invented; but it can only be applied to attractions by a very circuitous method. Lastly, Mr. Cuthbertson, an admirable artist in all machinery connected with electricity, has invented a curious electrometer for measuring the charges of large batteries and jars: it in fact consists of Henley's electrometer, Lane's dis-

443. If we suppose that the effects of the condenser are combined with those of Cavallo's electrometer, we shall have an idea of the fourth instrument, to which Volta has assigned a destination remarkable enough, by employing it to determine the effects of Galvanic electricity, of which we shall speak in our second volume. The part of this instrument which performs the office of an electrometer is composed of two bits of straw *or*, *os*, (fig. 47), which must be equal and quite straight. They are suspended by means of two thin metallic wires terminated by hooks, which play freely in two little holes made in the inferior extremity of a small piece of metal, whose opposite extremity is soldered beneath the stopple of the jar *fhk*. Above the same stopple is cemented a plate or disc of brass *cd* furnished below with a metallic wire terminated by a globule *g*. To this disc has been given the name of *collecting plate*, because its use is to gather together such small quantities of electric fluid as we wish to render sensible by their accumulation. This plate or table supports another *ab*, to which is attached a glass cylinder *mn*, and which communicates with the surrounding bodies by means of a slip of metal *ily* curved in such a manner that it does not come too near the collecting plate. Each plate is varnished on the face that is in contact with the other. The jar carries upon its exterior surface a graduation *tz*, from which the separation of the two straws according to lines such as *op*, *ux*, may be estimated nearly; but which is not proper to give the measure of the electric force whence that separation results: for, independently of the little precision of such a measure considered in itself, it is not in a constant relation

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charging electrometer considerably improved, and an improvement of Brooke's steelyard electrometer; a very judicious combination which possesses many advantages. Mr. Cuthbertson's own description of this instrument, with an account of some curious experiments made with batteries by means of it, may be seen in vol. ii. of the quarto series of the *Philosophical Journal*. Tr.

with the force, which follows the inverse ratio of the square of the distance, and whose action is altered in the present case by the effect of gravity, which solicits the straws in a direction contrary to that of the separation produced by the electricity.

In proportion as the collecting plate shall receive successively, at the place of the globule *g*, small quantities of electric fluid, by the repeated contacts of the substance furnishing that fluid, which we shall suppose to be that of vitreous electricity, there will be made a decomposition of the natural fluid contained in the upper plate *ab*; so that the resinous fluid attracted towards the collecting plate will be detained by the coats of varnish interposed between the two discs, while the vitreous fluid will escape by the metallic slip *ily*. After a certain number of contacts the upper plate *a b* is lifted up, and immediately the straws separate from one another, when, to ascertain the species of electricity with which they are animated, and at the same time that which has been resigned to the collecting plate, the means must be employed which we have pointed out while speaking of Cavallo's electrometer.

In the instrument we have just been describing the collecting plate represents the metallic disc of the common condenser, and the superior plate produces the same effect as the piece of marble; with this difference, that the fluids move freely therein, and that the obstacle which prevents one of them from passing into the collecting plate is an intermediary idio-electric substance.

On Natural Electricity.

444. The analogy between the electric fluid and the matter of thunder had already been conjectured by different philosophers, when Franklin, after having ascertained the influence of points, of which we have before

treated (415), proposed to set up in the air an iron rod terminated by a sharp point, as a mean of verifying that analogy. Dalibard was one of the first who put the idea of Franklin into execution. He caused to be constructed near Marly a cabin, above which was fixed an iron rod of 13 métres or 40 French feet in length, insulated at the bottom. A thunder cloud having passed in the vicinity of that bar, it emitted sparks at the approach of the finger, and exhibited the effects of the usual conductors which we electrify by the help of our machines.

445. Romas, who cultivated natural philosophy at Lille, was afterwards impelled by his ardour and courage to the point of sending up to the cloud itself a paper-kite armed with a rod that terminated in a point. The cord of the kite was interlaced with a metallic wire to within a certain distance of the point at which it was held, and the remainder was a little silk cord destined to keep the apparatus insulated and to preserve the observer from the explosion. He saw spontaneous jets of light issue from this apparatus, of 32 decimetres or 10 feet in length, and whose report was similar to that of a pistol. The dangers of all experiments of this kind are so evident, even supposing every precaution attended to, that they can only be undertaken by those in whom curiosity has vanquished fear. Several philosophers, thrown down and injured by the shocks they received on drawing sparks from an apparatus communicating with the interior of their apartment, have repented of inviting so formidable a guest. The celebrated Richman, professor of Natural Philosophy at Petersburgh, lost his life there in circumstances which seemed intended to make the lesson more impressive. He was killed by the very apparatus which was meant to measure the force of the electricity of clouds.

446. Franklin in suggesting and effecting the bringing down of lightning from the clouds, proposed to himself an object more truly philosophical than that of merely making electrical experiments. He thought that if he

placed upon a building an iron rod terminated by a sharp point, and established a communication between that rod and the bosom of the earth, it might preserve the building from an explosion by draining off the fluid of the thunder clouds which passed in its neighbourhood. Pursuant to this idea, himself and others have constructed in various places instruments for this purpose; instruments to which the French have given the name of *Paratonnerres*, and the English, of *Thunder-guards*, Thunder-rods, or Conducting-rods.

Beyer, a French artist, advantageously known for the versatility of his talents, but who has especially directed his attention to the construction of thunder-guards, proposed to terminate the bar of such an instrument by a point of platina, that being a metal at once very unyielding and exempt from oxydation. He employs for conductors, a kind of cords formed of iron wires plaited and coated over with a layer of grease. Such a cord is prolonged to the edge of a well, where it is attached to an iron rod whose inferior extremity is immersed in the water. The adoption of this conducting matter has the advantage of requiring much less time to establish the communication between the rod and the common reservoir, and to diminish with regard to the edifice itself, the injuries and consequent repairs inseparable from an operation of this nature.

447. Among philosophers some have considered the advantages of thunder-rods as incontestable; while others have thought that their action must be too weak to protect the edifice which carries them: it is, say they, as if you would by means of a slender tube divert the stream of a great river ready to overflow its banks. Some have even affirmed that thunder-rods were better calculated to provoke the descent of the lightning upon the building than to prevent it. But the utility of these instruments cannot well be doubted, especially since experience has taught us that an explosion, which otherwise appeared inevitable,

has been made upon the very point of a conducting rod, without causing the least damage to the edifice (*p*). Some years ago there was presented to the French Academy of Sciences the rod of a thunder-guard on which the lightning had fallen, and whose point was blunted and seemed to have been in a state of fusion. The electric fluid had followed the communication established between the iron rod and the bosom of the earth, and the house had been preserved untouched.

When it is proposed to erect thunder-rods upon edifices of a tolerable extent, their number must be multiplied. They ought not, however, to be too near one another, because in that case they would mutually weaken each other's effects; just, as we have seen (417) that several points situated at small respective distances hinder one another from drawing off the electric fluid. On the other hand, they must be so near that their different spheres of activity shall not leave any intermediate space: now, we have concluded that the radius of such a sphere should be about 10 metres or 30 feet; and hence it would suffice if we allowed a distance of 20 metres or about 60 feet between one thunder-rod and another.

It may be seen from what we have been saying, that the effect of the thunder-guard is not limited to the silently drawing down the electric fluid; though its services even in this respect are not to be despised: but its decisive moment is that when, every thing announcing an immediate explosion, it presents itself to receive it, and causes the fluid to pursue the route traced for it beforehand by the philosopher on the side of the edifice, which is thus freed from the shock caused by the report.

(*p*) It has been disputed whether conducting rods should be terminated by points or by knobs; and the dispute found its way among the members of our Royal Society, where, being probably intermingled with personal and political motives, it led to topics which were for some time discussed with a warmth unbecoming the votaries of genuine philosophy. Some account of this dispute may be seen under the article POINT, in *Hutton's Dictionary*, and THUNDER in the *Sup. Ency. Britan.* TR.

448. Among the different ways in which the explosion of lightning may become fatal to those who are found upon a spot of ground visited by a storm, there is one which at first view would seem inexplicable. It consists in this, that it is possible for a man or an animal situated far from the place where the lightning flashes, to be nevertheless exposed to great danger, or even to loss of life, in consequence of the explosion; and various examples of this secret action (if we may so call it) of lightning have been related. Lord Mahon, now Earl Stanhope, a learned English philosopher, who in his Treatise on Electricity has directed much of his attention towards this singular effect, founds its explication upon a re-establishing of the equilibrium to which he has given the name of the *returning stroke* *, and which we shall proceed to elucidate, reducing to the theory of two fluids the point of view under which we shall contemplate it.

Let *a b* (fig. 48) be the conductor of a common machine whose parts are put into motion in the usual way: let us suppose that behind this conductor a second *c d* is placed, insulated and at such a distance that it cannot draw any spark from the former: lastly, let us suppose a third conductor *e f*, not insulated, to be situated so near the second that when it is electrised the third shall draw off sparks. Of the two fluids which constitute the natural fluid of *c d*, that of the resinous electricity will remain in that body in virtue of the attraction exerted upon it by the vitreous fluid of *a b*; the other, namely the fluid of the vitreous electricity, will be repelled into the body *e f*, which will transmit it to the surrounding bodies, so that the conductor *c d* will be electrised resinously. If at this moment the conductor *a b* be discharged, the following *c d* will rapidly retake its vitreous fluid which will be restored to it through the intervention of the conductor *e f*; and if we suppose instead of the conductor *c d*, an

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* Principles of Electricity, 1781. pa. 69, 76, et seq.

insulated person who presents his hands at a suitable distance from the conductors *a b*, *e f*, the discharge will create between *ef* and the finger situated on the same side a very sharp spark, produced by the sudden reentrance of the vitreous fluid which had issued from the body of the person. Among the different modes of proving the returning stroke pointed out by Earl Stanhope, we have chosen this, because it exhibits the case where the effect is most sensible.

Now it may be conceived that if the electricity of the conductor *a b* were extremely powerful, the returning stroke would still obtain even in the supposition where nothing more was in presence of that conductor than the single body *c d* which was not insulated; and such is the case which occurs in nature, when the shock is occasioned by a thunder cloud.

449. Let N G (fig. 49. pl. VIII.) represent one of these clouds strongly charged with vitreous electricity, and D a traveller situated in the sphere of activity of that cloud. The vitreous fluid of the man will be driven into the earth by the repulsion of the fluid contained in that cloud, so that the traveller will be in a very decided state of resinous electricity. Just at this moment the presence of some terrestrial object C will cause the cloud to make an explosion: the vitreous fluid will then repass into the body of the traveller with a rapidity and an abundance proportional to the energy with which the electricity of the cloud acted, and the resulting shock may be sufficiently powerful to kill the unfortunate man: at the same time it will be possible that men or animals at the places *f*, *b*, &c. which would appear more exposed to the danger of the explosion, should not receive the slightest stroke (*q*).

(*q*) From the time that Franklin drew down the electric fluid from the clouds, (for he not merely suggested but *accomplished* this, about the same period as Dalibard and others succeeded in the attempt), the thunder,

2. *Electricity produced by Heat.*

450. Independently of all the phenomena which we have considered hitherto, and which appertain entirely to

the lightning, and the rain of storms, have been regarded as electric phenomena. But in the present state of philosophical knowledge, the vague explanations usually given upon these assumed principles cannot satisfy a philosopher; besides that they are insufficient to account for those sudden and in a manner instantaneous showers which characterise thunder storms. As it is not very probable that the electric fluid is the sole agent employed by nature in such storms, various attempts have been lately made to trace the several causes which combine in their production. One of the most successful explorers of this region of physics appears to have been M. Libes, who is of opinion that the phenomena in question are occasioned by the combined influence of hydrogen, oxygen, and the electric spark. The train of his reasoning from acknowledged facts is this:

The torrid zone is the ordinary theatre of thunder-storms; at 40 or 50 degrees of latitude, they seldom occur out of the summer season; and near the poles they scarcely occur at all. The rain of the storm is accompanied by lightning; and preceded by a period of heat which greatly facilitates the decomposition of water: there must therefore be a great quantity of disengaged hydrogen, which is raised into the superior parts of the atmosphere; and this hydrogen, when passing into the gaseous state, carries with it a great quantity of electricity. Now it cannot be doubted that lightning is produced by the electric fluid. But as to the rain which is formed at the moment when the lightning traverses the air, it can only arise from two causes: either from the sudden precipitation of the water which was dispersed in the atmosphere; or from a combination of the oxygen and hydrogen gas occasioned by the electric spark. Libes considers these two effects separately. The rain of a storm he remarks takes place very frequently without there having been previously any cloud to disturb the transparency of the atmosphere; yet it cannot be supposed that the water, which is in very small quantity, and perfectly dissolved in the air, can be so precipitated at once as to form an abundant rain. Hence he recurs, on the contrary, to the electric spark, which in its passage, effected with an inconceivable rapidity, meets with mixtures of oxygen and hydrogen gas, the combination of whose bases becomes effected and gives birth to violent explosions, as well as to a quantity of rain proportional to the quantity of aeriform fluids that have served to produce the shower. This hypothesis explains very well, how there may be lightning without natural philosophy, there are several which are shared between physics and natural history. We shall at present refrain from speaking of the electricity produced by the torpedo and some other fishes, which contain a particular organ, wherein resides the faculty of exciting motions and producing a phenomenon similar to that of the Leyden phial. This subject will be better placed in that part of the work where we shall treat of the influence of *Galvanism* upon the animal economy. The only topic we mean to consider here is the electric virtue acquired by certain minerals through the influence of heat, which in this case produces the same effect as friction does upon ordinary idio-electric bodies. This point of physical mineralogy is so much the more interesting as the distribution of the electric matter in the minerals we are speaking of, has a very great analogy with that of the magnetic matter in iron in the loadstone state; in such manner that these minerals offer the true term of comparison between electricity and magnetism.

451. Each of the minerals in question has always at least two points, of which one is the seat of vitreous, the other that of resinous electricity. To these points, which are always situated in two opposite parts of the mineral,

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thunder, though there may be many clouds in the air; and why there should be many thunder storms in hot countries, while there are but few in cold ones, where the production of hydrogen gas is very trifling: it is likewise perfectly consistent with Libes's theory of the aurora borealis described in note (*p*) par. 628, vol. ii.

The subject of Natural Electricity has been pursued much farther by several authors than by M. Haüy: the inquisitive reader may consult *Franklin's Letters*, *Beccaria—Lettre dell' Ellettricessimo*, *Priestley's History of Electricity*, the article Thunder in the *Supplement to the Ency. Britan.*, and, for an interesting statement of facts and inferences relative to fiery meteors, shooting stars, &c., a paper by Sir Charles Blagden in the 74th vol. of the *Philosophical Transactions*. Some philosophers have deduced from their researches into this subject, a comparatively simple process for dissipating storms, by the exploding of gunpowder, the combustion of resinous masses, &c. which has been sometimes employed with success. See *Mag. Encyclopedique*, for 1806, tom. ii. or *Phil. Magazine*, No. 103. Tr.

we shall give the name of *electric poles*. To distinguish these poles one from the other, a very simple apparatus may be adopted, the description of which follows. It consists of a needle *m n* (fig. 50) of silver or of brass, terminated by two globules, and moveable upon a pivot which forms the upper part of a stem *c a* of the same metal. This stem with the needle are insulated by placing them upon a cylindrical support *s* of resin. Then place a finger of the left hand upon the shield or lump that terminates the stem at bottom, and taking into the right hand a stick *g* of gum lac or of sealing wax which has been rubbed, present it, during a second or two, at a small distance from the stem *a c*; then withdraw first the finger, afterwards the stick *g*. Thus will the needle be found electrised resinously; in such manner that, according as we bring near to one of the globules *m*, *n*, the resinous or the vitreous pole of a mineral electrised by heat, the globule is attracted or repelled. The reason of the process employed to electrise the needle may be comprehended, by applying here what we have said of the manner in which the same effect is produced, in relation to the electrometer of Cavallo (441). The electricity of the needle will be preserved a quarter of an hour or more; and we may, while generating it, render it either very sensible or very weak, (according as it may be required for the experiment proposed) by varying the distance between the stem *a c* and the stick of lac or of wax.

452. Let us commence with the example of the stone called *tourmalin*, being the first in which the property of becoming electric by heat was traced, and which crystallises in prisms usually of nine plane sides, terminated by summits with three, six, nine, or more faces. When this stone is at the ordinary temperature, it is only susceptible of being electrified by friction, and in that case the part rubbed always acquires vitreous electricity, like what obtains for all bodies of a vitreous nature. But if a tourmalin be exposed for a short time to the action of fire,

holding it with pincers by the middle of the prism; and if its two extremities be afterwards presented alternately to the little globe *m* or *n*, we shall observe that the one attracts and the other repels that globe, from which we may ascertain the poles wherein the respective electricities reside. Now it may be conceived that the tourmalin, having only its natural quantity of fluid, which is alone decomposed, if its vitreous pole is turned towards the globule, it will be in the same case as if it were solicited singly by a quantity of vitreous fluid whose force was equal to the difference between the forces of its two poles, arising from the different distances at which they act: therefore the globule will be repelled. Similar reasoning will prove that, on the contrary, attraction ought to be evinced, if the tourmalin is presented to the globule by its resinous pole.

But if the needle *m n* were not insulated, it is easy to conceive that the presence of either of the poles of the tourmalin would generate, in the globule nearest to that pole, an electricity contrary to its own; whence it follows that the globule would, in this case, be constantly attracted.

453. If one of the poles of the tourmalin be presented to light bodies, such as grains of ashes, or sawdust, each grain, becoming in like manner a little electric body, whose part turned towards the pole which acts upon it has acquired a contrary electricity to that of such pole, will be carried towards the tourmalin. Having arrived at contact, it will generally remain applied there; for the fluid of the tourmalin, which is a non-conducting body, not being able to communicate itself to the light body, all will continue in the same state as before. It often enough happens, however, that some of these grains are repelled as soon as they have touched the stone. This effect obtains when the minute body has met with some ferruginous or other conducting moleculæ, situated at the surface of the tourmalin. In such case, if it be supposed

for example that this molecule possessed the resinous electricity, a portion of its fluid will pass to the contiguous part of the little body, which is occupied by the vitreous fluid, and will unite itself with that fluid, on neutralising it. Then the resinous fluid which enveloped the other part of the little body finding itself in excess, that body will be entirely in the resinous state; whence it must follow, that the conducting molecule, which is in a similar state, will repel it. Hence we see in what manner those authors must be understood who assert, that the tourmalin attracted and repelled indifferently by its two ends, without producing those constant effects of attraction on one side, and repulsion on the other, which we have ascribed to it. These latter effects only take place with a tourmalin placed opposite a body which is already itself in a certain state of electricity. The others, which are variable, have respect to the case where the bodies on which the tourmalin acts were previously in their natural state.

454. In a tourmalin the electric densities diminish rapidly in departing from the extremities, so that they are nothing, or next to nothing, in a sensible space situated towards the middle of the prism: of consequence, the centres of action are situated near the extremities. This distribution is analogous to that of the electric fluid diffused about a cylinder, as we have represented it in a former paragraph (399). It may be rendered perceptible to a certain degree, by moving a tourmalin to and fro that has one of its faces opposite one of the globules of the little needle: we shall observe that this globule has a marked tendency towards one point of the stone; but when it corresponds with the mean part, so that the two centres of action are each equally remote from it, we shall not find any motion, except a mere fluttering, given to the globule.

455. Let T (fig. 51) be a tourmalin having its centre of resinous action placed at A, and its centre of vitreous action at *a*. Take a stick of sealing-wax at the end of which

there is fixed a silk thread of about a centimetre, or four and a half lines, in length, by heating the wax at that end and inserting one extremity of the thread in the part thus melted. If after having rubbed the sealing-wax, in which case the free extremity of the thread will acquire resinous electricity, that same extremity be brought in presence of the point R of the tourmalin, and if at the same time the latter be made to receive little alternate motions from right to left, and reciprocally, the thread will be seen to bend itself in a contrary direction, to avoid the point R; and if the stick be brought a little nearer the tourmalin, the thread will incline all at once, by a curvilinear motion, towards the point A. If we afterwards present to the thread the points situated a little beyond A, and all the succeeding ones between that and the opposite extremity U, attraction will be manifested throughout. But if a thread possessing vitreous electricity be employed, such as that which should be attached to a glass tube which had been rubbed; on presenting it towards the extremity U it will avoid going on to touch that extremity by inclining towards the point *a*; and all the points situated between *a* and the extremity R, will act upon it by attraction: so that we shall not have precisely the inverse of the preceding effects, because in both cases the thread is attracted by the middle part of the tourmalin. This species of paradox however will be unravelled by considering that, the mean part being in the natural state, at the moment when it is presented to the thread, it will attract such thread indifferently, whatever be the kind of electricity which solicits it; in such manner that in the two cases the effect of this attraction adds itself to that of the centre of action which acts upon the thread by an electricity contrary to its own.

456. Two tourmalins presented one to another, mutually attract by the poles animated with contrary electricities, and repel mutually by the poles which shew the same kind of electricity. We have already demonstrated these results when speaking of the reciprocal actions of two

idio-electric bodies, whose natural fluid shall have undergone a decomposition (411). But here we may verify the theory by experiment: in order to which, we heat two tourmalins, and after having laid one of them across upon a flat piece of cork floating at the surface of some water, we select one of its poles and to it present successively the two poles of the tourmalin. When the poles thus brought near to one another have different electricities, we shall see the floating tourmalin move towards the other, and follow it in all its motions. If, on the contrary, the neighbouring poles are solicited by opposite electricities, the floating tourmalin will turn about to present itself to the other by the contrary pole, and then approach to it in virtue of the attraction. Those who should assist at these experiments without having been previously instructed, would be tempted to take them for experiments in magnetism.

457. The tourmalin begins to evince electricity, when it has arrived at a certain elevation of temperature, which Æpinus places between the 30th and the 80th degree on Reaumur's thermometer ($99\frac{1}{2}$° and 212,° F.) But among bodies of this species there exist some to which we need only, as it were, shew fire, that they should manifest their electricity. If the tourmalin be more and more heated, there will be a term where it will cease to yield signs of the electric virtue. It often happens that after having withdrawn it from the fire, we are obliged to leave it to return of itself to a moderate temperature, that it should have any action upon the little bodies which are presented to it. But it would seem that beyond the term where its electricity has become insensible through the action of too strong a heat, there is another where its effects are reproduced in an inverse sense. We have caused the foci of two burning glasses to fall upon the extremities of a tourmalin, and have observed that each pole, after

having acquired its ordinary electricity, would next cease to act, and lastly would pass to the opposite state; so that the attraction, after having become zero, would give place to repulsion, or reciprocally.

458. If a tourmalin be broken at the moment when it manifests its electricity, each fragment, however small it may be, has its two moieties in two opposite states, in like manner as the entire tourmalin; which must, at first, appear very singular, since this fragment, supposing for example it were situated at one of the extremities of the stone still whole, would then be solicited only by a single kind of electricity. This difficulty may be happily resolved by the help of a very plausible hypothesis similar to that advanced by Coulomb with regard to such magnetic bodies as present the same singularity, that is to say, by considering every integrant particle of a tourmalin to be itself a little tourmalin provided with its two poles. It hence results that in the entire tourmalin there will be a series of poles alternately vitreous and resinous; and such are the quantities of free fluid which appertain to these different poles, that in all the half of the tourmalin yet unbroken, which manifests the vitreous electricity, the vitreous poles of the integrant moleculæ are superior in force to the resinous poles in contact with them; while the contrary obtains in the half which manifests the resinous electricity: whence it follows that the tourmalin is in the same state (speaking generally) as if each of its halves were only solicited by quantities of vitreous or resinous fluid equal to the differences between the fluids of the neighbouring poles. Now, if the stone be cut at any place whatever, as the section can only take place *between* two moleculæ, the part detached will necessarily commence with a pole of one kind, and terminate with a pole of a contrary nature. We shall give a more complete developement of this explication when we treat of magnetism.

459. Such bodies as are susceptible of becoming electrised by heat, present, relatively to their forms, a new singularity, which seems to announce a mutual dependence between their crystallisation and their electric property. We know that in general the way in which nature elaborates crystals is subjected to the law of the greatest simplicity, in so far that the opposite and corresponding parts are similar, with regard to the number, the disposition, and the figure of their faces. But the forms of crystals that become electric by heat deviate from this symmetry, in such manner that the parts in which the two electricities reside, though similarly situated at the two extremities of the crystal, differ in their configuration; one of them undergoing decrements which are evanescent upon the opposite part, or to which decrements correspond that are subjected to another law; a circumstance which may enable an observer to predict beforehand, simply from the inspection of the crystal, on what side either species of electricity will be found, when the crystal shall be submitted to the test of experiment. Thus in the variety of the tourmalin which we shall call *isogone*, and which is represented by fig. 52, the shape is that of a prism of nine plane sides, terminated at one end by a summit having three faces, and at the other by a summit having six faces; and experiments prove that the first summit is the seat of resinous electricity, while the second manifests vitreous electricity.

460. But of all the crystals that exhibit this correlation between the exterior configuration and the electric virtue, the most remarkable are those which appertain to an acidulating substance named *borate of magnesia*, whose form is, generally, that of a cube incomplete on all its edges, and farther modified by facets corresponding to the solid angles. Here the two electricities act according to the directions of four axes, each of which passes through two opposite solid angles of the cube

which is the primitive form. In one of the varieties (fig. 53) which we shall call *defective*, one of the two solid angles situated at the extremities of the same axis is entire, the other has given way to a facet *s*. Now resinous electricity is evinced at the angle which has not undergone any alteration, and vitreous electricity at the facet which supplies the place of the opposite angle; thus making eight electric poles, four for each species of electricity. In another variety (fig. 54) the solid angles analogous to those of the preceding which were supplied by the facets, continue to present the same modification. The other angles situated similarly to those which were entire, are here replaced each by a like facet *s′*; but if it existed alone, the symmetry would be found re-established, while the law of the phenomenon requires that it should be altered. Therefore, three other facets *r*, *r*, *r*, are observed to be situated about each of the former; so that the angles which they modify, present, in this respect, a kind of superabundance, in consequence of which this variety has been denominated *superabundant borate of magnesia* (*r*).

(*r*) Since the publication of this Treatise our author has been enabled farther to pursue his researches into the properties of this kind of crystals, and that his labours have not been entirely misemployed may be learned from the following extract from the *Tableau Methodique*, &c. of J. A. H. Lucas:—" The examination of topaz crystals, including both the new varieties of form, (viz. the *Octosexdecimal* aluminous fluate of silica, and the *Perioctaëdral* aluminous fluate of silica with a sexdecimal summit), has conducted M. Haüy to two interesting results. The first variety has enabled him to verify a conjecture which his observations on the electricity of several other mineral substances, and particularly the tourmalin and borate of magnesia, rendered extremely plausible, and which nature appears to take a pleasure in confirming; namely, that the secondary forms of such minerals as are capable of becoming electric by heat always deviate from the rules of symmetry, at the same time that the two summits always acquire two opposite states of electricity. The second variety has presented him with new proofs of an electric phenomenon, which seems to be nearly allied to that which is exhibited by magnets with con-

We may now ask whether, in the midst of the imposing apparatus of our artificial machines, and of that diversity of phenomena which it presents to the astonished eye, there is any thing more calculated to excite the interest of philosophers than these little electrical instruments executed by crystallisation, than this combination of distinct and contrary actions, confined within a crystal whose greatest dimension is probably less than a twelfth of an inch? And here the observation we have so often previously made recurs to the mind with additional force, that those productions of nature which seem desirous to conceal themselves from our notice, are they which may reward us most liberally for a closer examination.

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secutive points. 'It is,' says he, 'an additional instance of resemblance 'between the appearances produced by magnetism, and those which are 'especially exhibited by bodies susceptible of electricity by heat; and in 'which the law of the electric densities is so completely analogous to that 'observed by the magnetic densities in the artificial magnet.'"—See also par. 568, vol. ii. TR.

END OF THE FIRST VOLUME.

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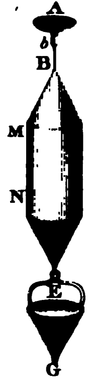
Pl.I.

Fig. 2.



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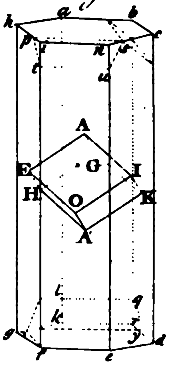

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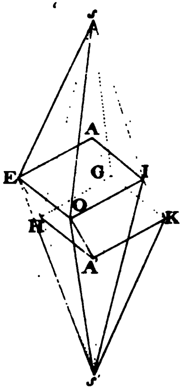

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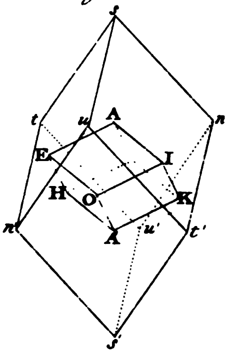

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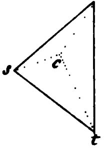

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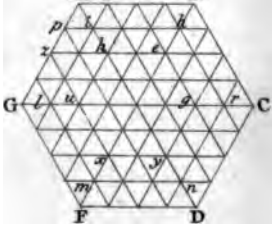

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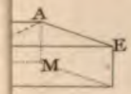

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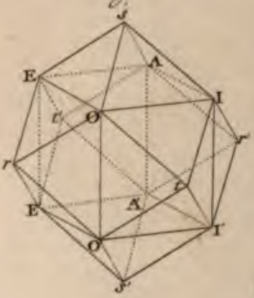

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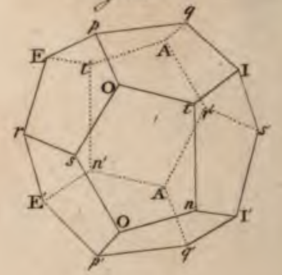

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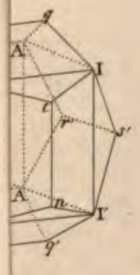

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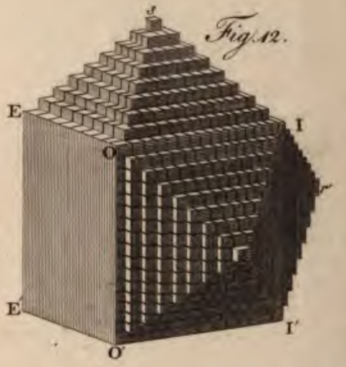

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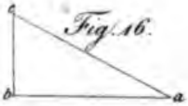
Pl. III.



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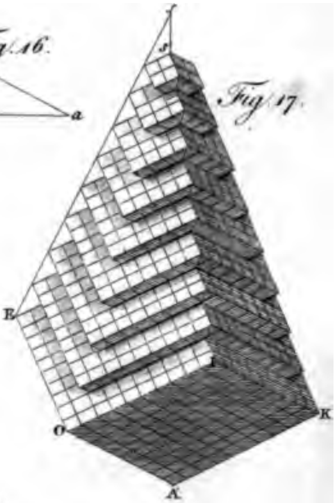

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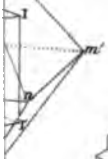

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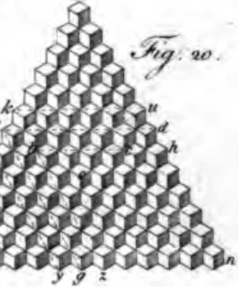

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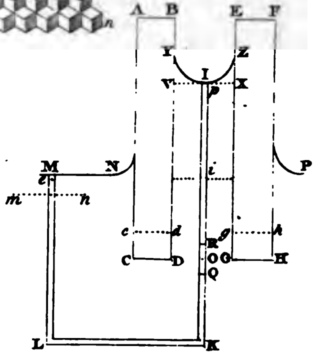

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Pl. IV

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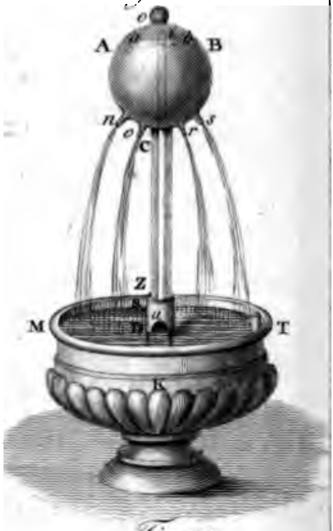
g. 25.

Fig. 26.



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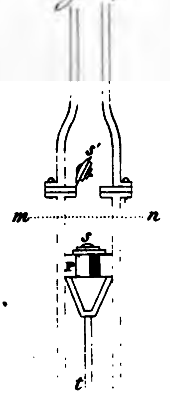

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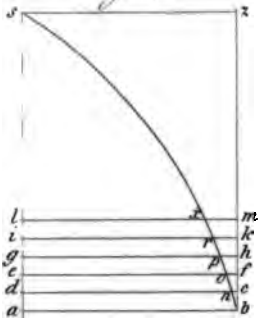

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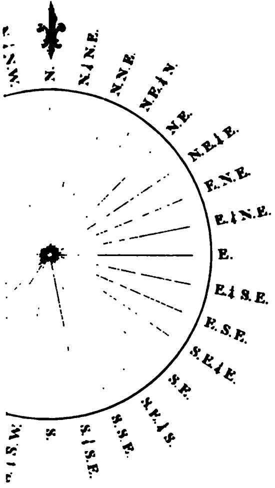

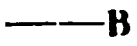

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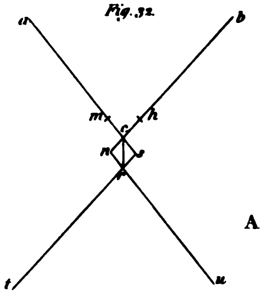

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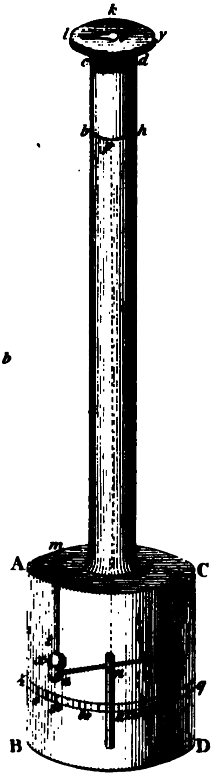


Barlow sculp.

Fig. 36

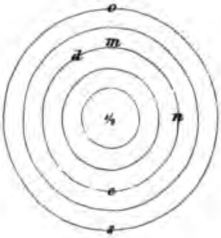
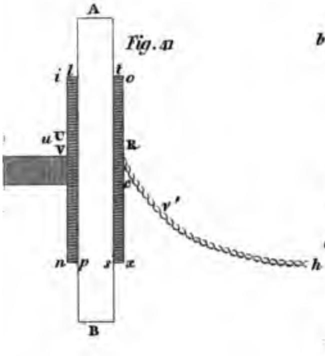


Fig. 38

Fig. 41



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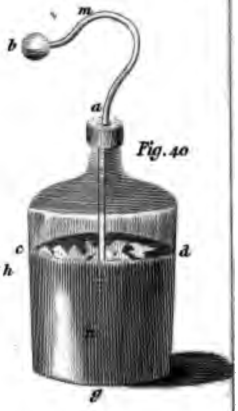

Pl.VII

Pl.V